(2)

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

WORKLOAD MEASURES FOR NAVY INVENTORY CONTROL POINTS

by

Edgardo T. deGuia

September 1988

Thesis Advisor: Alan W. McMasters

Approved for public release; distribution is unlimited

Unclassified

security classification of this page

AD-A201860

REPORT DOCUMENTATION PAGE

1a Report Security Classification Unclassified	1b Restrictive Markings
2a Security Classification Authority	3 Distribution Availability of Report
2b Declassification Downgrading Schedule	Approved for public release; distribution is unlimited.
4 Performing Organization Report Number(s)	5 Monitoring Organization Report Number(s)
6a Name of Performing Organization Naval Postgraduate School / 6b Office Symbol *(if applicable)* 30	7a Name of Monitoring Organization Naval Postgraduate School
6c Address *(city, state, and ZIP code)* Monterey, CA 93943-5000	7b Address *(city, state, and ZIP code)* Monterey, CA 93943-5000
8a Name of Funding Sponsoring Organization / 8b Office Symbol *(if applicable)*	9 Procurement Instrument Identification Number
8c Address *(city, state, and ZIP code)*	10 Source of Funding Numbers: Program Element No / Project No / Task No / Work Unit Accession No

11 Title *(include security classification)* WORKLOAD MEASURES FOR NAVY INVENTORY CONTROL POINTS

12 Personal Author(s) Edgardo T. de Guia

13a Type of Report	13b Time Covered	14 Date of Report *(year, month, day)*	15 Page Count
Master's Thesis	From To	September 1988	73

16 Supplementary Notation The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17 Cosati Codes			18 Subject Terms *(continue on reverse if necessary and identify by block number)*
Field	Group	Subgroup	Measurement, Workload, Inventory Control Points

19 Abstract *(continue on reverse if necessary and identify by block number)*

The Operations and Maintenance, Navy (O&MN) budget for the two Navy Inventory Control Points (ICP's) has shown an overall increase over the past 15 years. However, the numerous outputs or workload measures being used at the ICP's do not seem to show the same trend as O&MN. The Naval Supply Systems Command (NAVSUP) wants to relate the budget to the various workload measures. In fact, NAVSUP would like a single measure of workload applicable to the two ICP's which could explain most of the behavior of O&MN. This measure of workload could serve as a simple but useful predictive tool for budget requests. This thesis examined data for O&MN and workload indicators representing the major functions performed by each ICP. The data covered the time interval from 1973 to 1987. Models using single and multiple variables were then developed through exploratory data analysis and regression analysis in an attempt to describe how O&MN is related to or can be explained by the workload indicators. The models using only a single workload measure did not do very well at explaining the behavior of O&MN, although if a single variable model must be chosen, the number of repairable line items appeared to be the best O&MN predictor. The multivariate models were too data limited to be useful immediately. However, the potential for developing accurate models using multiple variables appears to be very good. (KR)

20 Distribution Availability of Abstract ☒ unclassified unlimited ☐ same as report ☐ DTIC users	21 Abstract Security Classification Unclassified	
22a Name of Responsible Individual Alan W. McMasters	22b Telephone *(include Area code)* (408) 646-2678	22c Office Symbol 54Mg

DD FORM 1473,84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete — security classification of this page

Unclassified

Workload Measures For Navy Inventory Control Points

by

Edgardo T. de Guia
Lieutenant, Supply Corps, United States Navy
B.S., University of the Philippines 1974

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1988

Author: E T de Guia
Edgardo T. de Guia

Approved by: Alan W. McMasters
Alan W. McMasters, Thesis Advisor

Dan C Boger
Dan C. Boger, Second Reader

P. Purdue
Peter Purdue, Chairman,
Department of Operations Research

Kneale T. Marshall
Kneale T. Marshall,
Dean of Information and Policy Sciences

ABSTRACT

The Operations and Maintenance, Navy (O&MN) budget for the two Navy Inventory Control Points (ICP's) has shown an overall increase over the past 15 years. However, the numerous outputs or workload measures being used at the ICP's do not seem to show the same trend as O&MN. The Naval Supply Systems Command (NAVSUP) wants to relate the budget to the various workload measures. In fact, NAVSUP would like a single measure of workload applicable to the two ICP's which could explain most of the behavior of O&MN. This measure of workload could serve as a simple but useful predictive tool for budget requests. This thesis examined data for O&MN and workload indicators representing the major functions performed by each ICP. The data covered the time interval from 1973 to 1987. Models using single and multiple variables were then developed through exploratory data analysis and regression analysis in an attempt to describe how O&MN is related to or can be explained by the workload indicators. The models using only a single workload measure did not do very well at explaining the behavior of O&MN, although if a single variable model must be chosen, the number of repairable line items appeared to be the best O&MN predictor. The multivariate models were too data limited to be useful immediately. However, the potential for developing accurate models using multiple variables appears to be very good.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

A. BACKGROUND

1. Naval Supply Systems Command (NAVSUP)

Under the authority of the Secretary of the Navy, NAVSUP directs the operation of the Navy supply system. Its mission is to develop, manage and operate the Navy supply system to provide supplies and services to satisfy peacetime and wartime fleet and other customer mission requirements. Support of the Naval operating forces and the maritime strategy is the ultimate objective of every task and function performed by NAVSUP. [Ref. 1]

2. Inventory Control Points (ICP)

The inventory management responsibilities of NAVSUP are implemented through ICP's. There are two Navy ICP's: Ships Parts Control Center (SPCC) for maritime applications and Aviation Supply Office (ASO) for aviation applications. Their missions and goals are to:

1. Provide worldwide acquisition and control of weapons systems and material.
2. Provide total life cycle configuration management, logistics support data, and supply support for assigned weapons systems.
3. Provide inventory management for assigned secondary items.
4. Contribute to the readiness and sustainability of the fleet. [Refs. 2,3]

To accomplish these, the ICP's perform similar major functions in the areas of Inventory Management, Customer Support, Purchasing Actions, and System Provisioning. On the resource side, both activities use Operations and Maintenance, Navy (O&MN) funds to finance their operations.

3. Inputs and Outputs

Figure 1 shows the activities of an ICP during a particular fiscal year. The ICP uses its resources of O&MN and End Strength (number of personnel) to perform its major functions of Inventory Management, Purchasing, and Provisioning. How an ICP performs is mainly reflected through a performance indicator known as Supply Material Availability or SMA. This is a measure of the annual percent of requisitions received which are filled immediately. Several outputs indicate the amount of work done by an ICP. Clearly, there is quite a diversity of outputs which makes it seem unlikely that only one could serve to forecast O&MN input requirement.

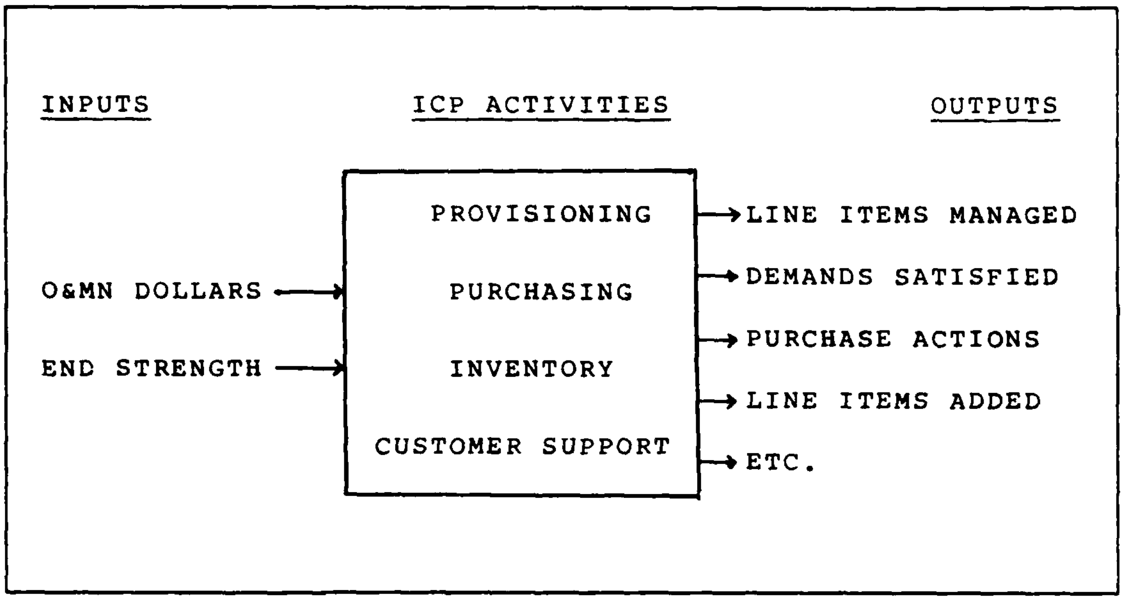

Figure 1. Inputs and Outputs at a Navy ICP during a Fiscal Year.

4. Measures Of Workload

The concern over measures of workload for the ICP's was originally raised by Rear Admiral James B. Whitaker, then Deputy Commander for Systems Integrity (SUP 00X) at the Naval Supply Systems Command (NAVSUP), Washington, D.C. He stated that "although the Operations and Maintenance (O&MN) budget has shown an overall increase after years of operation, most workload indicators actually decreased " [Ref. 4]. The increase shown by O&MN is not just the effect of inflation. When annual O&MN obligations were converted to their equivalent FY 87 dollars as part of this thesis, there was an overall increase of more than 50 percent for both ASO and SPCC from 1973 to 1987. Admiral Whitaker further expressed his interest in "finding out what is the single workload measure that drives the ICP into their level of spending " [Ref. 4]. If such a single variable can be found, a predictive model could be developed to use in the budgeting and operational planning process by NAVSUP. Such a model could answer questions like

1. If a certain level of workload is desired from the ICP, how much O&MN funding is needed?
2. If a certain level of funding is authorized for the ICP, what level of workload is expected?

While one may be desirable, there presently exists no single measure of workload that encompasses all ICP functions [Ref. 5].

B. OBJECTIVE

The objective of this thesis is to determine by using exploratory data analysis and regression analysis if there is a single workload indicator which can explain the behavior of O&MN for both ICP's. However, if a single variable model can not be found, then multiple variable models will be considered and the simplest of those identified.

C. SCOPE

This thesis will use annual and quarterly workload indicators from both of the Navy ICP's. The number of observations of these indicators is constrained by the availability of data. Since there is no prescribed time as to how long reports and files must be kept by the ICP's, the indicators may not have the same number of observations. All indicators are related to the major functions performed by the ICP's to accomplish their missions.

D. PREVIEW

Chapter II presents the various single variable models which will be tested and describes how to evaluate the goodness of a given model. Chapter III presents the results of single variable analyses and discusses the inadequacy of using single variable models. Chapter IV presents the multiple variable models which will be tested and the results of the multiple variable analyses. Chapter V presents a summary of this thesis, conclusions and recommendations.

II. MODELS WITH A SINGLE INDEPENDENT VARIABLE

This chapter will apply the typical steps taken in a statistically based investigation of sets of data to build a model which will relate outputs to needed O&MN funds. Throughout this thesis, O&MN funds will be referred to as the dependent variable and all others will be referred to as candidate independent or explanatory variables.

A. STEPS

1. Determination of Variables

Every variable considered should conceptually have an impact on the stated strategic plan of NAVSUP and missions of the ICP. It must also have relevance to the major functions performed by the ICP's and somehow contribute to their measure of effectiveness which is Supply Material Availability (SMA). The candidate explanatory variables were determined by the following methods:

1. Interviews were conducted with NAVSUP and ICP personnel from different functional groups and work levels.
2. NAVSUPNOTE 5200 provided a listing of workload profile indicators that should be used in NAVSUP activities.
3. Several manuals and instructions were studied to obtain a better perspective of ICP organizations and functions.

The variables used in this thesis grouped in accordance with the major functions performed by an ICP are listed below.

a. List Of Candidate Variables For SPCC

1. Inputs
    a. Annual and Quarterly O&MN
    b. Annual NSF Obligations (NSF)
    c. Annual End Strength (E/S)
2. Outputs
    a. Inventory Management. 1H Cog line items make up most of the consumable material managed by SPCC while 7 Cog line items make up most of the repairable line items.
        1) Annual and Quarterly Total line items (TOTAL L.I.)
        2) Annual and Quarterly 1H Cog line items (1H COG L.I.)
        3) Annual and Quarterly 7 Cog line items (7 COG L.I.)

4) Annual and Quarterly Repairable line items (REP L.I.)

b. Customer Support. Demands are in number of units.

1) Annual and Quarterly Total demands (TOTAL DEM)

2) Annual and Quarterly Demands for 1H COG items (1H COG DEM)

3) Annual and Quarterly Demands for 7 COG items (7 COG DEM)

c. Purchase actions. Beginning in FY 1983, the cut-off amount between small and large purchase changed from under $10,000 to under $25,000.

1) Annual Total purchase (TOT PURCH) actions

2) Annual Small purchase (SM PURCH) actions

3) Annual Large purchase (LG PURCH) actions

4) Annual Purchase for stock (STK PURCH) actions

5) Annual Purchase for spot requirements (SPOT PURCH) actions

6) Annual Purchase actions for consumable line items (CONS PURCH)

7) Annual Purchase actions for repairable line items (REP PURCH)

d. System Provisioning. Provisioning includes the determination of the range and depth of spare parts required to support a weapons system in its life cycle. When new equipment is inducted into the Navy inventory, this usually results in the addition of line items managed by an ICP. When an equipment is removed from the inventory (say, when it becomes obsolete) this results in deletion of line items.

1) Annual Number of Items added to current inventory (ITEM ADD)

2) Annual Number of Items deleted from current inventory (ITEMS DEL)

e. Performance Indicators

1) Annual and Quarterly Supply Material Availability (SMA)

2) Annual Number of Backorders (BB) established per year

3) Annual Material Outstanding Obligations (MOOS) at the end of a fiscal year

b. List Of Candidate Variables For ASO

1. Inputs

a. Annual and Quarterly OMN

b. Annual NSF Obligations (NSF)

c. Annual End Strength (E/S)

2. Outputs

a. Inventory Management. 1R Cog line items make up most of the consumable material managed by ASO while 7R Cog line items make up most of the repairable line items. 7R Cog line items are aeronautical Depot Level Repairables

(DLR) while Repairable line items is the totality of all Aviation DLR's managed by ASO.

1) Annual and Quarterly Total line items (TOTAL L.I.)

2) Annual and Quarterly 1R Cog line items (1R L.I.)

3) Annual and Quarterly 7R Cog line items (7R L.I.)

4) Annual and Quarterly Repairable line items (REP L.I.)

5) Annual and Quarterly Program Support Items (PSI)

b. Customer Support. Demands are in number of units.

1) Annual and Quarterly Total Demands (TOTAL DEM)
2) Annual Demands for 1R COG items (1R COG DEM)
3) Annual Demands for 7R COG items (7R COG DEM)

c. Purchase actions. Beginning in FY 1983, the cut-off amount between small and large purchase changed from under $10,000 to under $25,000.

1) Annual Total purchase (TOTAL PURCH) actions

2) Annual Small Purchase (SM PURCH) actions

3) Annual Large Purchase (LG PURCH) actions

d. Performance Indicators

1) Annual and Quarterly Supply Material Availability (SMA)

2) Annual Number of Backorders (BB) established per year

3) Annual Material Outstanding Obligations (MOOS) at the end of a fiscal year

2. Collection Of Available Data

Collection was done manually with the figures coming from retained reports and files. Some data could date back as far 1973 while some were only for the last two years. Only a few data have both annual and quarterly figures available. It is anticipated that there will be more fluctuations in quarterly data as spending of budgets may follow a seasonal effect. On the other hand, annual figures will show smoother trends because things tend to even out in the course of the year. Overall, the data collected is a good representation of the major functions performed by the ICP's.

In view of the scarcity of data, anything available was collected. In most cases, a workload indicator was broken down into its subsets ; i.e., Number of line items into Total, Consumables and Repairables. Some variables could also be considered as performance indicators such as Supply Material Availability, Backorders and Material Obligations Outstanding. O&MN and Navy Stock Fund (NSF) obligations were converted to FY 87 dollars using inflation factors before they are used in any analysis. Original

data can be found in Appendices A to D. Appendices A and B show the annual data by fiscal year for SPCC and ASO, respectively. The values of O&MN and NSF during the years in which they were obligated are listed along with the constant dollar indexes and the corresponding constant dollar amounts. Appendices C and D contain quarterly data for SPCC and ASO, respectively. The data in the appendices are also grouped in accordance with the time intervals of the observations.

3. Data Analysis

Exploratory Data Analysis will be used to acquire a basic understanding of data sets. Plots of variables against time will show the general trend of the variables. Whether SPCC and ASO are similar or not can be shown graphically.

Scatter plots of O&MN against each workload indicator will show if the relationship is linear or non-linear. If non-linear, the scatter plot may even suggest a suitable transformation of the variables to express the relationship in a linear form. If a pattern can not be clearly determined graphically, a formal correlation analysis will be performed.

The purpose of correlation analysis is to find out how strong the relationship is between two variables as measured by the coefficient of correlation, r. The value of r ranges from -1.0 for a strong negative correlation, 0 for no correlation, and +1.0 for a strong positive correlation. A test of hypothesis at the .05 level of significance will be conducted on the coefficient of correlation where the null hypothesis will claim that r is equal to zero. Variables which do not show favorable correlation with O&MN will not be used in regression analysis. The test statistics [Ref. 6] will be:

a. $$t = r \times \frac{\sqrt{n-2}}{\sqrt{1-r^2}} \quad \text{for } n \leq 50, \tag{1}$$

where

r = coefficient of correlation,

n = sample size,

t = t-statistic with n-2 degrees of freedom.

b. $$z = r \times \sqrt{n-1} \quad \text{for } n > 50, \tag{2}$$

where

z = value of the standard normal deviate.

4. Model Building

Data for O&MN and those workload indicators reflecting favorable correlation statistics will be fitted to different regression models and the goodness of fit will be evaluated using the criteria described below. The simple linear model will be initially used and then, based on the scatter plots and residual analysis, either O&MN or the workload indicator or both will be transformed in a way that could "straighten" out the data. There are advantages in re-expressing the relationship between variables linearly. Interpretations are relatively easier and departures from fit are more clearly detected [Ref. 7].

a. Simple Linear Model

$$Y = \beta_0 + \beta_1 X + \varepsilon, \tag{3}$$

where

Y = value of the dependent variable, O&MN,

β_0 = Y-intercept or value of Y when X = 0,

β_1 = coefficient of the workload indicator,

X = value of a specific workload indicator,

ε = error or residual between the value of the dependent variable predicted by the regression equation, $\hat{Y} = \beta_0 + \beta_1 X$, and the actual value observed, Y. All errors are assumed to be independent and identically distributed normal random variables with a mean of zero and a variance of σ^2.

b. Power Model

$$Y = bX^m\varepsilon, \tag{4}$$

where

Y = value of the dependent variable, O&MN,

b,m = unknown parameters,

X = value of a specific workload indicator,

ε = error or residual.

This can be transformed to a linear equation by taking the natural logarithm of both sides[Ref. 8] as follows.

$$\ln Y = \ln b + m \ln X + \ln \varepsilon \tag{5}$$

The transformed model equation is now in the form of equation (3) and can be handled by linear regression.

c. Exponential Model

$$Y = be^{mX}\varepsilon, \tag{6}$$

where

Y = value of the dependent variable, O&MN,

b,m = unknown parameters,

X = value of a specific workload indicator,

ε = error or residual.

This can also be transformed to a linear equation by taking the natural logarithm of both sides[Ref. 8] as follows.

$$\ln Y = \ln b + mX + \ln \varepsilon. \tag{7}$$

d. Logarithmic Model

$$Y = \beta_0 + \beta_1 \ln X + \varepsilon, \tag{8}$$

where

Y = value of the dependent variable, O&MN,

β_0 = Y-intercept,

β_1 = coefficient of ln X,

X = value of a specific workload indicator,

ε = error or residual.

This is already in the format of equation (3) so this can be handled by linear regression.

e. Model of Several Functions of X

$$Y = \beta_0 + \beta_1 f(X) + \beta_2 g(X) + \ldots + \varepsilon, \tag{9}$$

where

Y = value of the dependent variable, O&MN,

$\beta_0, \beta_1, \beta_2$ = constants,

$f(X)$ = a function of the independent variable X,

$g(X)$ = another function of the independent variable X,

ε = error or residual.

An example is $Y = \beta_0 + \beta_1 X + \beta_2 X^2 + \beta_3 X^3 + \varepsilon$ which is a polynomial of third degree.

f. Models With Time Lags

The general format will be the same as the above equations but the X and Y variables will be paired using different time periods. This models are of interest since they will indicate how long before outputs or performance indicators show the result of resource expenditures. Examples are

$$Y_t = a + bf(X_{t-n}) + \varepsilon, \tag{10}$$

or

$$Y_t = a + bf(X_{t+n}) + \varepsilon, \tag{11}$$

where

t = a specific time in either quarter or year,

n = time lag in the same units as t.

5. Evaluation of Models

The following criteria will be used to evaluate how well any of the above models describes a particular set of data.

a. Coefficient of Determination

The proportion of the total variation in the dependent variable Y that is explained or accounted for by its relationship with the independent variable X is measured by the coefficient of determination, R^2. If there is a good fit, the value of R^2 will be near one. [Ref. 7]

b. Standard Deviation of the Residuals

This quantity, S, is an estimate of σ. It measures the magnitude of unexplained variation between the observed and fitted value of the dependent variable. Smaller values will indicate better accuracy of prediction by the fitted model.

c. Residual

One way to make a quick and informal check of the assumption that the errors of observations are independent is to examine the observed values of the residuals, $\varepsilon = \hat{Y}_t - Y_t$. The plots of residuals can indicate the nature of a misfit between the model and the data in a clear way and can constructively suggest an improved model. For a good fit, all residuals should be small and half should be positive and half should be negative.

Several types of residual plots can be used.[Ref.9] They are:

1. Plot of residuals against each explanatory variable. The presence of a curvilinear relationship suggests that a higher order term, perhaps quadratic in the explanatory variable should be added to the model.
2. Plot of residuals against predicted values from the fitted model. If the variance of the residuals seem to increase with the predicted values, a transformation of the dependent variable may be in order.
3. Normal plot of the residuals. Residuals should look pretty much like a sample from a normal distribution.
4. Plot of residuals against time. Data are often collected in time order so even if time is not one of the explanatory variables used in the model, these plots sometimes lead to the detection of unsuspected patterns due to time.[Ref. 9]

d. Test for Significance of Coefficients

A t-test for significance of each coefficient must be conducted. This serves to confirm the relationship between X and Y variables and that the coefficient being tested is not equal to zero. A significance level less than .05 is considered reasonable to indicate that the resulting coefficient is not equal to zero. However, the strength of the relationship between the dependent and independent variable will still depend on R^2.

B. COMPUTER PROGRAMS USED

Exploratory data analysis, regression analysis and all statistical computations for both single and multiple variable models were done on the IBM 3033 mainframe computer at the Naval Postgraduate School using GRAFSTAT, an interactive data analysis and graphics system and MINITAB, a general purpose data analysis system and statistical computing system.

C. ASSUMPTIONS.

Gross O&MN obligations and workload indicators will be used in this analysis. The ICP's receive O&MN funds from two sources. Direct O&MN is received from NAVSUP so that the ICP's can perform their missions. In addition, they perform tasks and services for Hardware Systems Commands (HSC); namely, the Naval Sea Systems Command and the Naval Air Systems Command, and receive Reimbursible O&MN. The work performed for the HSC's involves support for certain weapon systems of special interest which include Casualty Report (CASREP) support, requisition expediting, daily requisition processing and others. CASREP support involves expeditiously providing to the customer repair parts which are urgently needed to bring the system back to opera-

tional status. Lack of this CASREP repair parts in the fleet adversely affects the capability of a combat unit to perform its missions.

Reimbursible O&MN is not a small portion of the ICP's gross O&MN obligations (28% for SPCC and 11% for ASO for FY 87). However, it is extremely difficult to separate out that portion of any workload indicator attributable to Reimbursible O&MN. It is therefore assumed that the ICP produced the gross outputs and achieved overall performance indicators by using gross O&MN.

Since past data are not routinely kept for the purpose of future studies, the time intervals for various workload indicators are different. It will be assumed that more accurate information is obtained by using more observations. Therefore, the time interval that provides the most number of data points will be used.

ICP functions which do not have a known workload indicator, such as host activity and base security functions, will be assumed to be insignificant.

Several factors have significantly changed over the last ten years which affect the way the ICP's do business. Some of the most significant are:

1. Depot Level Repairables (DLR) COG migration.

   Until 1981, repairable components used by the fleet and shore establishments of the U.S. Navy were managed as free (to the customers) items. While this system provided the ultimate user with repairables without charge, it was difficult to manage and was determined to be uneconomical.

   In April 1981, stock funding of non-aviation DLR's began. This resulted in repairables being chargable to end users. In April 1985, aviation DLR's were included in the new system. The intent of this program is to improve the availability of these expensive and critical items for the fleet while reducing the overall cost to the system. This policy change increased the level and scope of managing repairables by an ICP.

2. Advocacy of Competition.

   The law requires maximum use of competition in all purchase actions. This is intended to ensure that the government pays for an item at a fair price and achieves cost savings. This tends to lengthen the amount of time spent by ICP's in initiating purchase actions because of additional steps involved.

3. Advances in Automation.

   Many tasks performed manually in an ICP have been automated, beginning in the late 1970's. However, it is difficult to determine how workload and performance indicators have benefited.

III. RESULTS OF SINGLE VARIABLE ANALYSIS

A. DATA ANALYSIS

1. A Look At The Two Inventory Control Points

The first concern in the data analysis was whether the two types of ICP's are similar enough to have a common measure of output that would relate well with O&MN dollars consumed. Although the two activities perform basically the same major functions and achieve the same goals, there are several factors which make them different. The customer base consists of ships and submarines for SPCC and aircraft for ASO. Corrective and preventive maintenance schedules are different among these communities. Because the mission profile and weapons systems used by customers differ to a great degree, it is to be expected that the support requirements will also be different. The approach that will initially be taken here is to find out if there is a systematic relationship among the variables of the two activities. Perhaps the difference can be expressed as a simple multiplicative or additive factor.

Figures 2 to 4 clearly shows the difference between SPCC and ASO over the last ten years. SPCC consistently used more O&MN and have more people in their operation. The trend indicates that the gap will continue to increase. ASO obligates more NSF and this is supported by the higher total demands from their customers. SPCC's total line items is much higher than ASO's and this may be a major reason for the higher end strength required to manage the items. SMA is almost the same for both activities and it seems that SMA increases with O&MN.

It is conclusive that SPCC and ASO are so distinctly different that it is impossible to establish a single variable which will measure their workload in the same manner. Since ASO and SPCC can not be treated as identical, their variables will be analyzed separately.

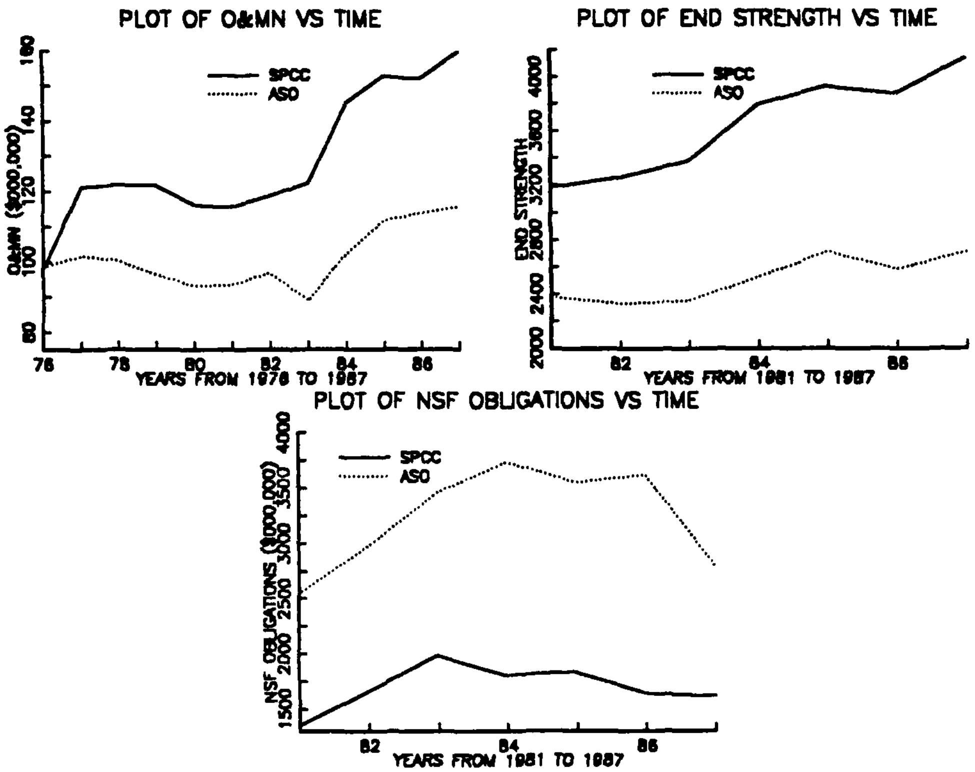

Figure 2. Graphical Comparison of ICP Resources.

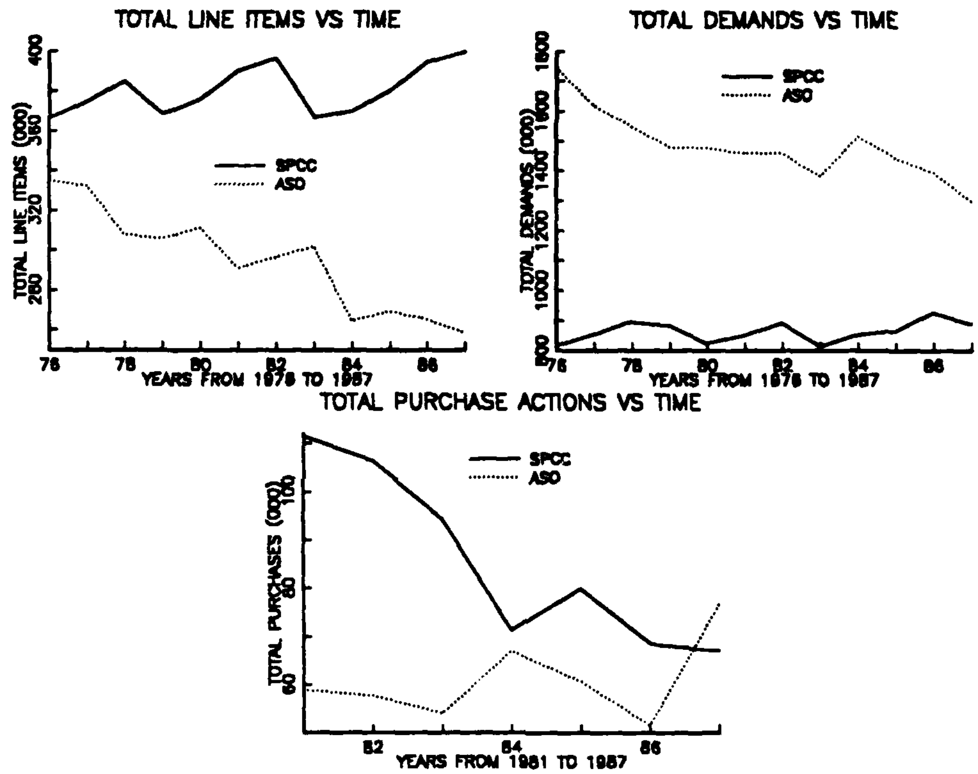

Figure 3. Graphical Comparison of ICP Major Workload Indicators.

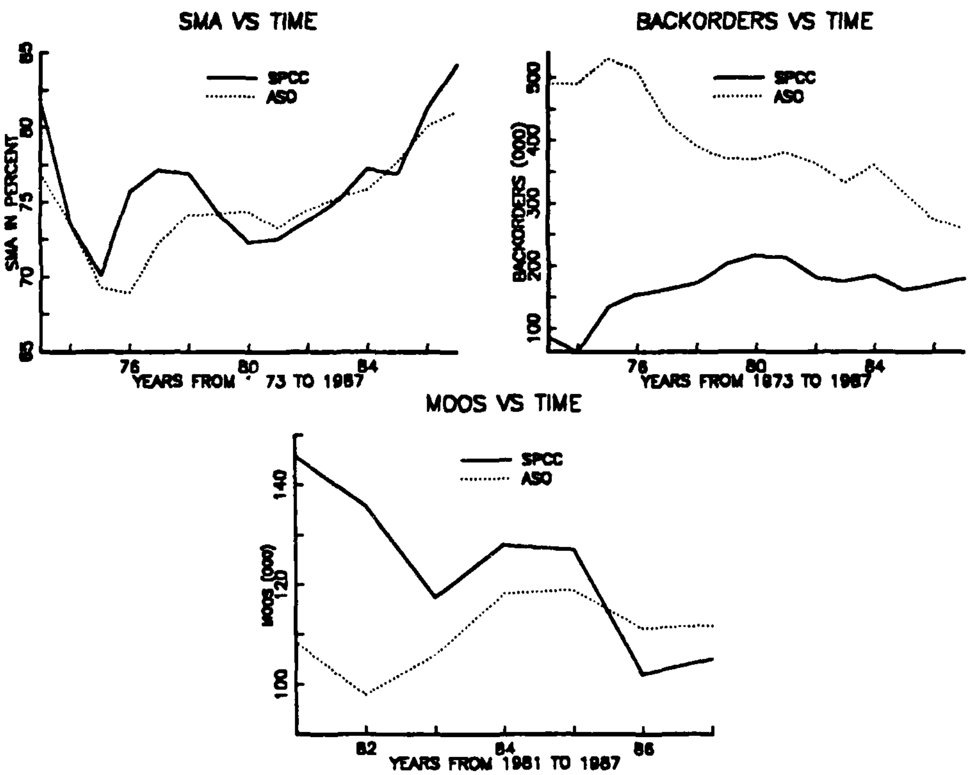

Figure 4. Graphical Comparison of ICP Performance Indicators.

2. Correlation Between Variables

Appendix E contains scatter plots of the dependent variable, O&MN, against each independent variable. It is evident that O&MN does not show a clear pattern or relationship with most of the variables. Most plots tend to be linear but the presence of wide variance and dispersion suggests that transformation of some variables may be necessary to obtain the best fit. Due to the large number of candidate variables only those with reasonable correlation with O&MN were carried on to the next step of model fitting. Some variables were confirmed to have no correlation at all with O&MN after applying the formal test for correlation. Some variables showed strong, negative but unfavorable correlation with O&MN and were eliminated. Some variables like number of Backorders can cause O&MN to increase although the variable itself is decreasing. It takes more effort and money to achieve a reduction in the number of backorders, and this is a good indicator of performance. On the other hand, when the total number of purchase actions decrease, there should be an accompanying reduction rather than an increase in O&MN because of smaller output. This matter was discussed with Commander Doug Hartman of NAVSUP and he concurred that the decreasing trend in the number of purchase actions is so significant that it can not be attributed to competition.

The number of demands is a function of equipment breakdown and availability of funds in the operating forces and is not controlled by the ICP's O&MN so it can still be used even with negative correlation with O&MN.

End Strength as a resource variable shows the strongest correlation with O&MN but it is almost synonymous with it because most of O&MN is used to pay for salaries of personnel. It was therefore dropped from the list of candidate explanatory variables.

NSF obligations which are believed to dictate the tempo and amount of work in NAVSUP activities did not show any correlation at all with the other variables.

At this point in the analysis, it can be concluded that, although the ICP's are using various workload indicators, many do not really relate well with O&MN. The following variables were considered to relate sufficiently that they will be used in the regression analysis.

1. Number of Line Items
2. Number of Demands
3. SMA

4. Backorders
5. MOOS

Plots of quarterly O&MN obligations and the major variables against time are shown in Figures 5 and 6. There appears to be no evidence of seasonality except perhaps in O&MN. Comparing the plots of annual data over time in Figures 1 to 3 and the plots of quarterly data over time in Figures 4 and 5, it appears that it will be more difficult to fit models to the quarterly data because they contain extreme random fluctuations. Data tend to even out during the course of the year and this explains the somewhat smoother curve for annual data. The significant decrease in the Total Line Items during the first quarter of FY 83 for SPCC and third quarter of FY 83 for ASO resulted from the Deputy Secretary of Defense (DEPSECDEF) Memorandum of 7 July 1981 which directed the armed services to transfer 200,000 consumable line items to Defense Logistics Agency (DLA) beginning in April 1982. The Navy's share of about 71,000 line items were distributed between the two ICP's: 41,000 for SPCC and 30,000 for ASO.

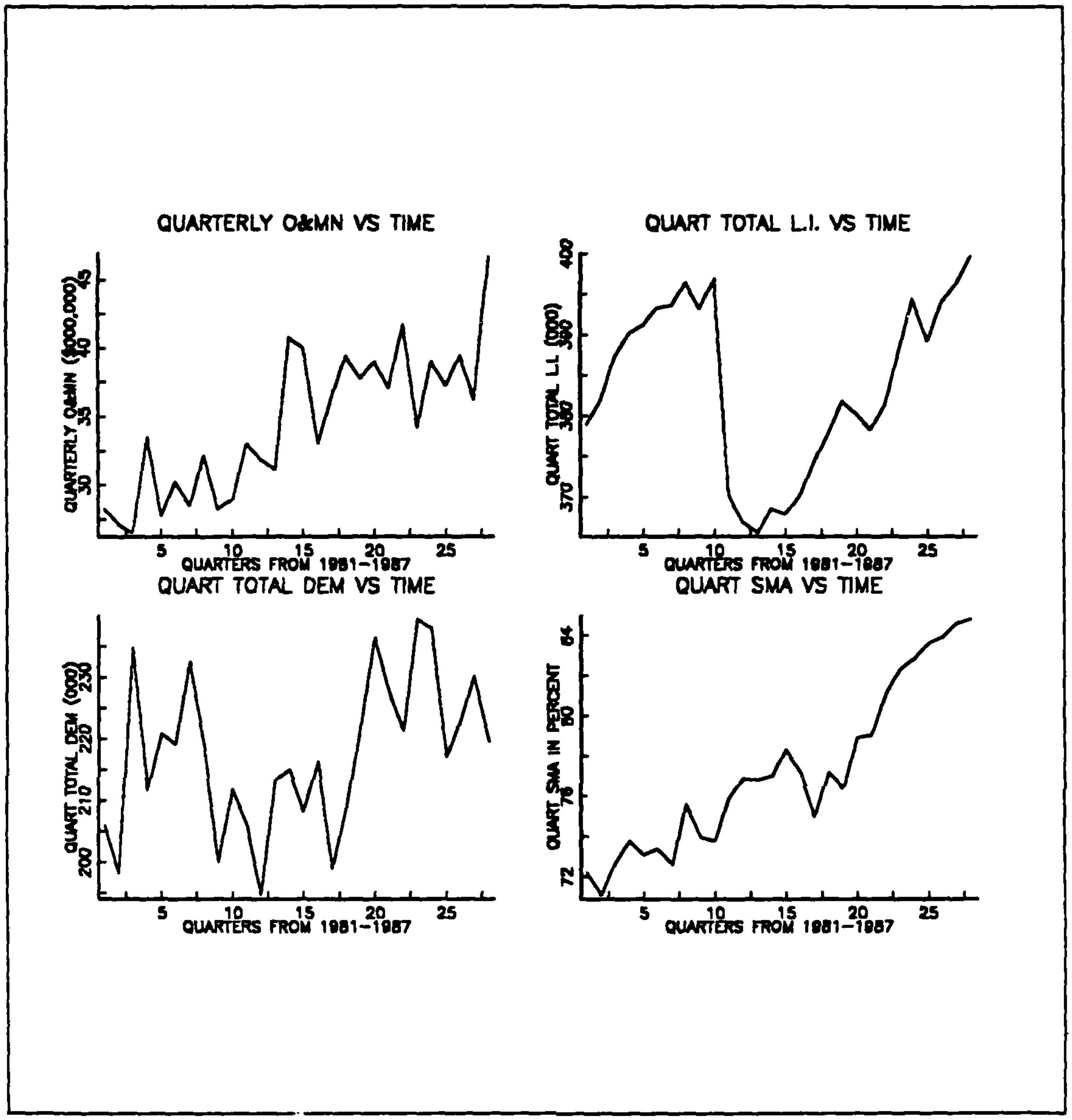

Figure 5. Plot of Major SPCC Quarterly Variables Against Time.

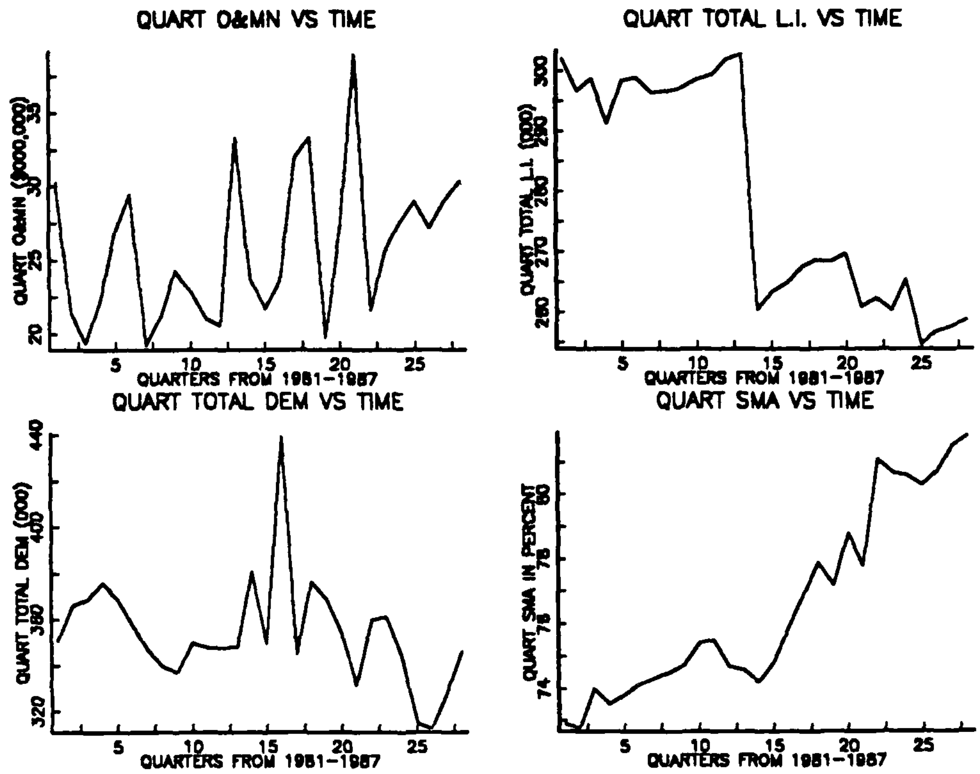

Figure 6. Plot of Major ASO Quarterly Variables Against Time.

B. REGRESSION ANALYSIS

The best models for each variable which passed the criteria mentioned in the first section of Chapter II are shown in Tables 1 through 4. The indicators are listed in the table according to the values of R^2. The variables with the highest R^2 ($R^2 \geq 20.0$) will be considered as the best indicators. The quarterly Repairable Line Items for ASO is listed although its R^2 is only 14.6 since it is the only ASO quarterly variable which passed the

criteria for test of significance. Plots of the resulting regression curves are shown in Figures 7, 8, and 9. The plot of residuals against each variable are also shown in Figures 7 through 9 and appear to show randomness and normality for all models. Note that Tables 1 and 2 correspond to annual values and Tables 3 and 4 to quarterly values.

As the tables and figures show, the effect on O&MN of all of the variables was basically described by the linear model but improvements were achieved by applying various transformations. The biggest improvement in the value of R^2 was achieved by the time lag model for the annual SMA for ASO, from 11.0 for no lag to 56.9 for a two year lag. Most of the increases in R^2 are small, about five percent on the average.

Overall, as can be seen from Tables 1 through 4, there are many workload indicators which can form statistically significant regression models to relate to O&MN. However, the variables which achieved the best fits with O&MN are from the group of Repairable Line Items. Thus, if only a single workload indicator was sought, the number of repairable line items is the best candidate. It is not surprising that Repairable Line Items are the leading indicators. The data are probably dominated by the effect of the major policy change of stockfunding of Depot Level Repairable which started in 1981 at SPCC and 1985 at ASO. The technological trend is also towards acquisition of additional complex and sophisticated weapons systems supported by repairable components.

The value of R^2 for all top indicators are rather low to be considered as reliable predictors. To have an idea of how these models would do when used in a prediction, consider the confidence interval for the best model, 7 COG Demand for SPCC. There is no data available for FY 88 which can be used for prediction. However, if the value of O&MN for FY 88 were to be predicted, with a standard deviation of the residuals equal to $9,439,000 and 10 degrees of freedom, the actual value is expected to be within plus or minus $21,000,000 of the estimated value at a confidence level of 95 percent. With SPCC's gross annual O&MN in the range of $150,000,000 this is a very wide interval to consider as accurate prediction.

Although the single variable models appear to be statistically significant by satisfying the criteria to be good models, their predictive abilities are unreliable. An alternative is to obtain more accurate models by using multiple variables in a model. This will be the topic in the next chapter.

Table 1. BEST FITS FOR LEADING SPCC ANNUAL INDICATORS.

VARIABLE	MODEL	COEFFICIENTS	T-STAT	SIG. LEVEL	TIME INTERVAL	R^2
7COG DEMAND	LINEAR	$\beta_0 = 87982$	11.72	3.65E-10	1976-1987	77.2
		$\beta_1 = .2133$	5.82	.00017		
7COG L.I.	EXPO	$\beta_0 = 10.731$	69.56	1.94E-16	1973-1987	75.5
		$\beta_1 = .00001$	6.33	.00003		
REP L.I.	LINEAR	$\beta_0 = -455$	-2.02	.06	1976-1987	71.5
		$\beta_1 = 1.4376$	5.01	.002		
SMA	LINEAR 1YR LAG	$\beta_0 = -176561$	-2.13	.05455	1973-1987	51.6
		$\beta_1 = 3903$	3.58	.00378		
TOTAL L.I.	POWER	$\beta_0 = -31.129$	-2.31	.0380	1973-1987	43.7
		$\beta_1 = 3.3355$	3.18	.0073		
1H COG L.I.	POWER	$\beta_0 = 8.0768$	6.95	.00001	1973-1987	42.8
		$\beta_1 = .2937$	3.12	.0082		
1H COG DEM	LOG	$\beta_0 = 2382159$	2.44	.03485	1976-1987	34.7
		$\beta_1 = -169410$	-2.31	.04351		
TOT DEM	POWER	$\beta_0 = -15.69$	-2.25	.05	1976-1987	32.3
		$\beta_1 = 2.01$	2.28	.05		

Table 2. BEST FITS FOR LEADING ASO ANNUAL INDICATORS.

VARIABLE	MODEL	COEFFICIENTS	T-STAT	SIG. LEVEL	TIME INTERVAL	R^2
REP L.I.	POLY (x^2)	$\beta_0 = 863070$	2.36	.0425	1976-1987	66.3
		$\beta_1 = 29.772$	2.21	.05		
		$\beta_2 = .00029$	2.33	.045		
SMA	LIN LAG 2YR	$\beta_0 = -775471$	-3.4	.00593	1973-1987	56.9
		$\beta_1 = 201587$	3.81	.00289		
TOTAL DEM	EXPO	$\beta_0 = 12.184$	59.78	1.39E-16	1973-1987	49.3
		$\beta_1 = .0000005$	3.55	.00356		
TOTAL L.I.	LOG	$\beta_0 = 896493$	3.07	.01184	1976-1987	42.6
		$\beta_1 = -63173$	-2.72	.02156		
BACK-ORDERS	LOG	$\beta_0 = 621435$	3.53	.0037	1973-1987	40.6
		$\beta_1 = -40812$	-2.98	.01064		
7R COG L.I.	LINEAR	$\beta_0 = 12356$	0.36	.72633	1976-1987	39.8
		$\beta_1 = 1.6595$	-2.57	.02879		
7R COG DEM	LINEAR	$\beta_0 = 46812$	2.06	.06	1973-1987	36.4
		$\beta_1 = .0862$	2.39	.045		
1R COG DEMAND	LINEAR	$\beta_0 = 157202$	6.93	.00001	1973-1987	35.8
		$\beta_1 = 1.05846$	-2.69	.01854		

Table 3. BEST FITS FOR LEADING SPCC QUARTERLY INDICATORS.

VARIABLE	*MODEL*	*COEFFICIENTS*	*T-STAT*	*SIG. LEVEL*	*TIME INTERVAL*	R^2
7COG DEMAND	EXPO	$\beta_0 = 10.032$	260.0	8.33E-17	1976-1987	63.3
		$\beta_1 = .000007$	9.01	8.29E-12		
7COG L.I.	EXPO	$\beta_0 = 9.426$	98.3	1.39E-16	1973-1987	59.1
		$\beta_1 = .000012$	9.23	4.74E-13		
1H COG L.I.	POLY (x^2)	$\beta_0 = 17357$	1.785	.07	1973-1987	45.4
		$\beta_1 = .51102$	4.247	.00008		
		$\beta_2 = .000001$	3.875	.00027		
REP L.I.	LINEAR	$\beta_0 = -5869$	-0.65	.52139	1981-1987	43.8
		$\beta_1 = .424$	4.5	.00013		
SMA	LINEAR	$\beta_0 = -37839$	-2.83	.00635	1976-1987	36.7
		$\beta_1 = 910.6$	5.22	2.43E-6		
TOTAL L.I.	POWER	$\beta_0 = -28.328$	-3.07	.0032	1973-1987	23.0
		$\beta_1 = 3.0089$	4.188	.000095		
1H COG DEMAND	LINEAR	$\beta_0 = 63955$	7.13	5.19E-9	1976-1987	21.6
		$\beta_1 = -.21404$	-3.59	.00079		

Table 4. BEST FIT FOR LEADING ASO QUARTERLY INDICATOR.

VARIABLE	*MODEL*	*COEFFICIENTS*	*T-STAT*	*SIG. LEVEL*	*TIME INTERVAL*	R^2
REP L.I.	EXPO	$\beta_0 = 8.3155$	9.59	1.22E-12	1981-1987	14.6
		$\beta_1 = .00026$	2.11	.04021		

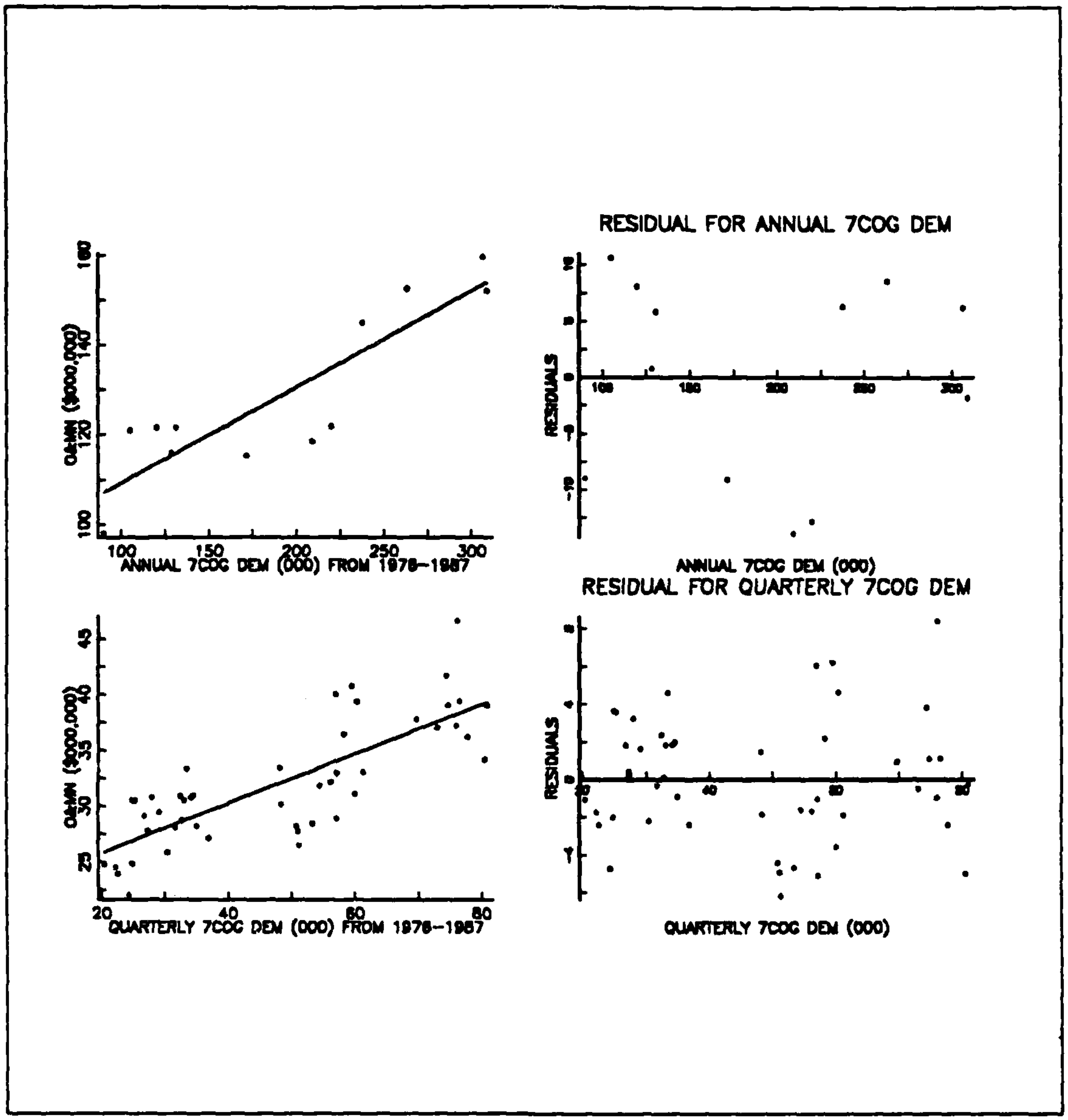

Figure 7. Model Fit and Residual Plots for the Leading Indicators of SPCC.

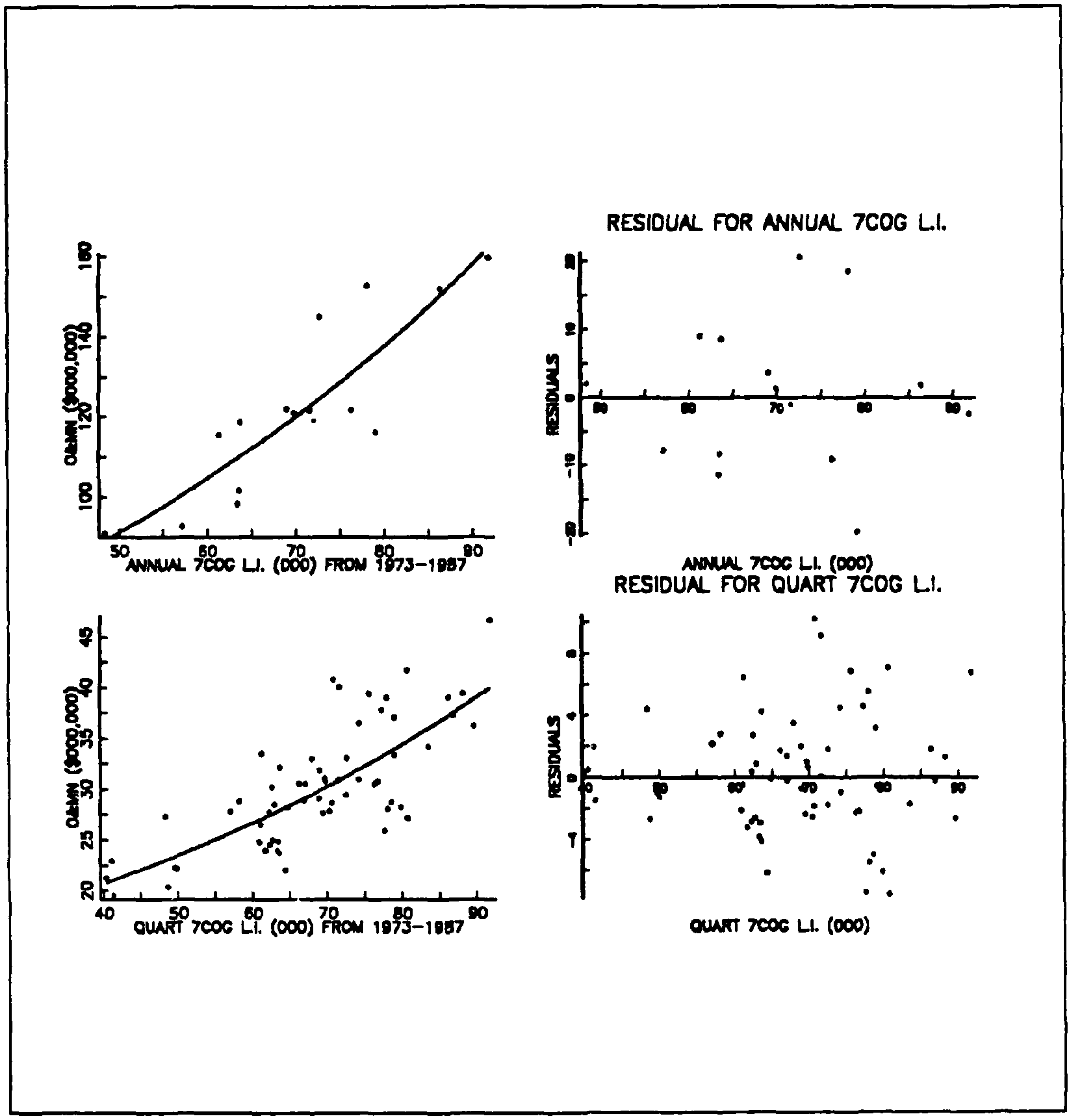

Figure 8. Model Fit and Residual Plots for the Leading Indicators of SPCC.

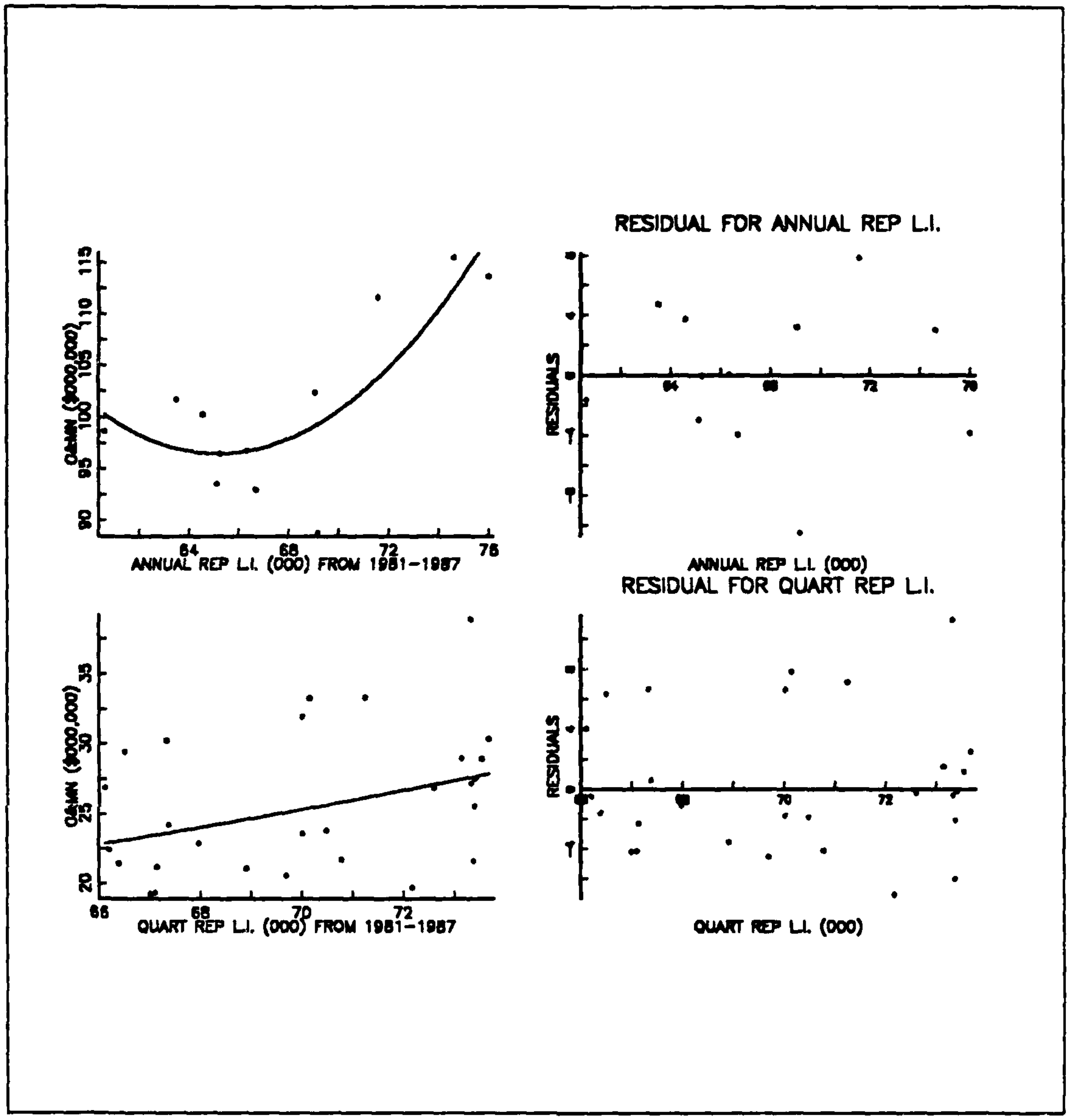

Figure 9. Model Fit and Residual Plots for the Leading Indicators of ASO.

IV. MULTIPLE REGRESSION MODEL

For models with multiple independent variables, all variables must have the same number of observations. In this chapter, annual and quarterly variables from two time intervals will be used for both ASO and SPCC. 1976-1987 provides many observations and allows the use of most of the variables. 1981-1987 allows the use of all variables but the number of variables that can be used in a regression model is limited to a maximum of five. There are only seven observations and it is required to have at least one degree of freedom in a regression equation. In spite of this limitation, the data for this time interval is worth looking at because it reflects the effect of such recent policy and procedural changes as the stockfunding of repairables.

A. GENERAL MODEL

The general form of the multiple regression model is

$$Y = \beta_0 + \beta_1 f(X_1) + \beta_2 g(X_2) + \beta_3 h(X_1, X_2) ... + \varepsilon, \tag{10}$$

where

Y	=	the dependent variable, O&MN,
β_i	=	constants
$f(X_1)$	=	a function of variable X_1,
$g(X_2)$	=	a function of variable X_2,
$h(X_1, X_2)$	=	a function of variables X_1 and X_2,
ε	=	error or residual.

An example of a function involving interaction of two independent variables is $f(X_1, X_2) = X_1X_2$.

B. METHODS

1. All Possible Regression

This is a cumbersome method especially if there are a lot of variables . The procedure involves running regression in sets of one, two, three and up to the maximum number of variables, say k, and recording the combinations with the highest R^2 in each set. These leaders are then examined for consistency in the pattern of variables. This is not a highly recommended method as the number of trials could go as high as 2^k. [Ref. 8]

2. Backward Elimination

When the sets of data allow, this is the most common practice in developing multiple regression models. The steps are:

1. Begin with all variables $X_1, X_2, X_3...X_k$.
2. Calculate the regression of Y on $X_1...X_k$.
3. Drop out each variable X_i which has a relatively insignificant t-statistic.
4. Recalculate the regression of Y on just the variables remaining. [Ref 10]

3. Forward Selection

This procedure is otherwise known as stepwise regression. A correlation matrix is used to select the variables which will be added to the regression model. The variable with the highest correlation with O&MN is selected first to be followed by variables with high correlation with O&MN but low correlation with variables already in the equation.

C. EVALUATION OF THE MODEL

The same criteria used in the single variable models above can be applied to multivariate models with two modifications:

1. Adjusted R^2 must be used to compensate for the different number of variables in the models.
2. An F-test must be conducted in order to test the significance of the overall model. A significance level less than .05 is considered reasonable to indicate that the overall model is reasonably valid.
3. The 95 percent confidence interval is included with the other results to show the predictive ability of the model.

D. RESULTS OF MULTIPLE VARIABLE ANALYSIS

1. Annual Variables For The Time Interval From 1976 to 1987

For the time interval from 1976 to 1987, there was a sufficient number of observations to use the backward elimination method. The best model for SPCC came out to be a linear combination of 7COG Line Items and 7COG Demands. These same variables were the leaders in the single variable models for SPCC. The results are summarized in Table 5. The regression equation is

$$O\&MN(SPCC) = 39222 + 0.816\ (7COGLI) + 0.154\ (7COGDEM).$$

Table 5. SUMMARY OF RESULTS FOR SPCC ANNUAL VARIABLES FROM 1976 TO 1987.

Predictor	Coef	Stdev	t-ratio	Sig. Level
Constant	39222	19058	2.06	0.069
7COGLI	0.8162	0.3034	2.69	0.025
7COGDEM	0.15416	0.03621	4.26	0.002

s = 7407 R-sq = 87.4% R-sq(adj) = 84.6%

Analysis of Variance

SOURCE	DF	SS	MS	Sig. Level
Regression	2	3416467200	1708233472	0.0001
Error	9	493809152	54867680	
Total	11	3910276352		

95% Confidence Interval: $\hat{Y} \pm$ $16,754,000

The formula used for the 95 percent confidence interval is $\hat{Y} \pm t_{(\alpha/2)} \times S$ where $\hat{Y}$ is the predicted O&MN, $t_{(\alpha/2)}$ is the t-statistic at $\alpha = .05$ and S = standard deviation. This interval indicates the range of the actual value that the dependent variable can take on as predicted by the regression equation.

The best model for ASO came out to be a linear combination of SMA and Backorders. SMA in this case did not have the time lag factor used in the single variable analysis. However, when SMA and Backorders were taken as single predictors for O&MN for this time interval 1976 to 1987, SMA resulted with R^2 of 43.4 and Backorder had an R^2 of 20.5. Although SMA and Backorder have a high negative correlation, they combine nicely to explain the behavior of O&MN for this time interval. The results are summarized in Table 6. The regression equation is

$$O\&MN(ASO) = -687881 + 8788(SMA) + 0.352(BB).$$

Table 6. SUMMARY OF RESULTS FOR ASO ANNUAL VARIABLES FROM 1976 TO 1987.

Predictor	Coef	Stdev	t-ratio	Sig. Level
Constant	-687881	106269	-6.47	0.0001
SMA	8788	1147	7.66	0.00003
BB	0.35248	0.05628	6.26	0.0001

s = 2917 R-sq = 90.4% R-sq(adj) = 88.3%

Analysis of Variance

SOURCE	DF	SS	MS	Sig. Level
Regression	2	720624384	360312064	0.0005
Error	9	76561616	8506846	
Total	11	797185792		

95% Confidence Interval: $\hat{Y} \pm \$6{,}600{,}000$

2. Annual variables For The Time Interval From 1981 to 1987

The forward selection method was the most suitable for this time interval because the number of variables exceeds the number of observations. The best model for SPCC came out to be a combination of Total Line Items, 7COG Demands, MOOS, and the squared quantity of 7COG Line Items. The results are summarized in Table 7. The regression equation is

$$O\&MN(SPCC) = 41095 + .000009(7COGLI)^2 - 0.430(TOTLI) + 0.368(7COGDEM) + 1.00(MOOS).$$

Table 7. SUMMARY OF RESULTS FOR SPCC ANNUAL VARIABLES FROM 1981 TO 1987.

Predictor	Coef	Stdev	t-ratio	Sig. Level
Constant	41095	29857	1.38	0.3016
7COGLI	0.00000854	0.00000189	4.51	0.0458
TOTLI	-0.42956	0.06905	-6.22	0.0249
7COGDEM	0.36834	0.06842	5.38	0.0329
MOOS	1.0032	0.1209	8.30	0.0142

s = 1911 R-sq = 99.6% R-sq(adj) = 98.9%

Analysis of Variance

SOURCE	DF	SS	MS	Sig. Level
Regression	4	2061276416	515319040	0.0116
Error	2	7304947	3652473	
Total	6	2068581120		

95% Confidence Interval: $\hat{Y} \pm \$8,200,000$

The best model for ASO came out be a linear combination of 1R COG Line Items, 7R COG Line Items, Total Line Items, 1R COG Demand, and 7R COG Demands. The results are summarized in Table 8. The regression equation is

$$O\&MN(ASO) = 132326 + 0.524(1RCOGLI) + 1.41(7RCOGLI) - 0.526(TOTLI) - 0.131(1RCOGDEM) + 0.104(7RCOGDEM).$$

Table 8. SUMMARY OF RESULTS FOR ASO ANNUAL VARIABLES FROM 1981 TO 1987.

Predictor	Coef	Stdev	t-ratio	Sig. Level
Constant	132326	524	252.62	0.0025
1RLI	0.524117	0.000900	582.03	0.0011
7RLI	1.41089	0.00431	327.64	0.0019
TOTLI	-0.526385	0.000667	-789.51	0.0008
1RDEM	-0.131244	0.000326	-402.49	0.0016
7RDEM	0.104432	0.000192	544.29	0.0012

s = 15.93 R-sq = 99.5% R-sq(adj) = 99.0%

Analysis of Variance

SOURCE	DF	SS	MS	Sig. Level
Regression	5	672386816	134477360	0.0018
Error	1	254	254	
Total	6	672386816		

95% Confidence Interval: $\hat{Y} \pm \$202,000$

Another combination of ASO annual variables which fitted well to a multiple model consist of 1R Line Items, 7R Line Items, 1R Demands, and Backorders. However, the coefficient for 7R Line Items becomes significant at a level of 0.0625 which is higher than the usual 0.05 used to reject the hypothesis that the coefficient is different from zero. The results are summarized in Table 9. The regression equation is

$$O\&MN(ASO) = 240447 - 0.482(1RCOGLI) - 3.47(7RCOGLI) + 0.314(1RCOGDEM) - 0.460(BB).$$

Table 9. SUMMARY OF RESULTS FOR ASO ANNUAL VARIABLES FROM 1981 TO 1987.

Predictor	Coef	Stdev	t-ratio	Sig. Level
Constant	240447	60381	3.98	0.0577
1RLI	-0.48233	0.08099	-5.96	0.0270
7RLI	-3.4736	0.9116	-3.81	0.0625
1RDEM	0.31395	0.03967	7.91	0.0156
BB	-0.45973	0.05693	-8.07	0.0150

s = 1928 R-sq = 98.9% R-sq(adj) = 96.7%

Analysis of Variance

SOURCE	DF	SS	MS	Sig. Level
Regression	4	664952576	166238144	0.03
Error	2	7434638	3717319	
Total	6	672387072		

95% Confidence Interval: $\hat{Y} \pm \$8,300,000$
This interval is bigger than the previous model.

All the above models appear to be good models based on the significance levels and R^2. However, their quality is restricted by the number of observations, or consequently, the degrees of freedom left when many variables are entered into the model. This causes the confidence interval to be extremely wide to be considered accurate for prediction. The validity of these models needs to be tested against data for FY 1988 before they can be considered practically useful. Usually, the data for the last period can be held over to test a model. However, the limited number of observations did not allow this procedure to be done in this thesis.

3. Quarterly Variables

The method of all possible regression was applied to the quarterly data for both ASO and SPCC for the periods of 1976 to 1987 and 1981 to 1987 but did not produce satisfactory results.

4. Time Series Regression

In order to test how the variables would relate over time, stepwise regression was performed for the annual data from 1976 to 1987 for both ASO and SPCC starting with observations from 1976 to 1981 then incrementing by one year until 1987. The results shown below indicate that the variables are very volatile; i.e., the leading indicators change with time. Only SPCC shows a consistent trend that 7COG Demands and Line Items have the best relationship with O&MN. The SPCC and ASO results for the period from 1976 to 1987 are the same models shown in pages 30 and 31.

Period	Leading Variables	R-Squared
1976-1981	Total Demand	56.81
1976-1982	Total Demand	53.32
1976-1983	No variable can form a good model	N/A
1976-1984	7COG Demands, 7COG Line Items, SMA	96.74
1976-1985	7COG Demands, 7COG Line Items, SMA	90.80
1976-1986	7COG Demands, 7COG Line Items	82.98
1976-1987	7COG Demands, 7COG Line Items	87.37

And the results for ASO are as follows:

Period	Leading Variables	R-Squared
1976-1981	1R Demand	76.83
1976-1982	1R Demand	67.85
1976-1983	1R Demand	80.85
1976-1984	Total Demands, Backorders	82.43
1976-1985	7R Demand, 1R Demand	90.56
1976-1986	7R Demand, 1R Demand, Repairable L.I.	93.29
1976-1987	SMA, Backorders	90.40

The significance of these time series models is that since the relationship of O&MN to the various variables changes with time, it may be extremely risky to forecast O&MN by a regression model using the workload indicators presently being used at Navy ICP's. It becomes even more unreliable when a model contains only one variable because the variable could lose its relative significance the following year.

V. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

This thesis applied data analysis and regression analysis to find a predictive model relating gross O&MN obligations by Navy ICP's to their workload indicators. Both single and multiple variable analyses were conducted on annual and quarterly data for ASO and SPCC to find the best model.

B. CONCLUSIONS

1. The two Navy ICP's are distinctly different and there is no systematic relationship between their variables. There is no single one which can serve as a common measure for both activities.
2. Many of the workload indicators being used by the ICP's do not really show favorable correlation with O&MN and thus, their usefulness as indicators is questionable. Correlation analysis showed that only the indicators related to the Number of Line Items, Number of Demands, Backorders, MOOS and SMA showed significant relationships with O&MN.
3. When data for the ICP's were analyzed separately using regression, the family of Repairable Line Items came out to be the major leading indicator for both activities. SPCC's O&MN has a linear relationship with 7 COG Line Items, a subset of Repairables, while ASO's O&MN has a quadratic relationship with the total number of Repairables.
4. Single variable models do not do very well at explaining the behavior of O&MN. One variable alone can not possibly capture the complexity of activities being conducted by an ICP.
5. Multiple variable models present a better alternative for forecasting O&MN. Unfortunately, there is not enough data to verify the validity of the models. More data needs to be obtained before the multiple variable models become practical to use.
6. ICP's are complex and dynamic activities where doing business requires constantly adapting to changes in policies and procedures caused by rapid advancement in technology and demand for the highest state of readiness in the armed forces while operating in an environment of constrained resources. The strength of relationship between the resource, O&MN, and the workload indicators can be expected to continue changing over time.

C. RECOMMENDATIONS

The leading indicators appear to be the family of Repairable Line Items and their Demands from customers. While the data for SPCC showed evidence that the effect of stockfunding of DLR's has stabilized, the data for ASO is still uncertain. This is understandable since SPCC started with this policy change almost five years earlier than ASO.

It is therefore recommended that data for the number of Repairable Line Items and their Demands be tracked annually for several more years and that data begin with the base years of 1981 for SPCC and 1985 for ASO. When the data appear to be settling down, then a more accurate predictive model may be developed. Meanwhile, as a short term alternative while accumulating more data, the best models presented in this thesis may be tested for their validity when FY 88 data becomes available.

All data for workload and performance indicators for the ICP's show what was done by personnel who performed work which directly affected the workload and performance indicators. On the other hand, O&MN data included costs for all personnel. As mentioned in Chapter 1, gross O&MN consist of direct O&MN from NAVSUP and reimbursibles from HSC's. This category of direct as presently applied to O&MN is too broad to allow breakdown between "direct" personnel, those who perform work which directly impacts workload indicators, and "indirect" personnel, those who perform support functions. The poor fits obtained in this study could be due to the presence of "indirect" personnel in the O&MN figures. There is a need to institute a personnel accounting scheme that enables measurement of "direct" versus "indirect" personnel. This might enable better fits between workload indicators and "direct" O&MN. Also, this categorization of "direct" and "indirect" personnel could serve as a management tool since a comparison of the trends between "direct" O&MN and a workload indicator can readily show the efficiency of work among "direct" personnel. An increase in the "indirect" O&MN may also indicate the amount of nonproductive work being done at the ICP's.

APPENDIX A. ANNUAL DATA FOR SPCC

YEAR	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
73	35642584	91085	81.7	3300	103579	48352	365464	86300	43277	72674
74	40239568	92739	73.7	3341	105809	57097	355963	64808	125071	75250
75	48706496	101514	70.1	3258	106132	63517	364223	134668	106280	93156
76	51256528	98211	75.7	3180	267263	63396	366691	155412	78795	86473
77	68492096	121032	77.2	3074	278920	69818	374699	163018	83320	78203
78	74718768	121672	76.9	3041	286891	71575	384947	173209	102431	103111
79	83071312	121752	74.2	3100	263275	76285	368481	202882	116113	107299
80	92050880	116138	72.3	3176	266067	79035	375948	216891	134601	92577
81	100327600	115439	72.5	3183	294675	61270	390120	214608	146000	111621
82	108396896	118687	73.7	3259	297225	63714	396475	183072	136000	106559
83	127927088	122021	75.1	3382	264191	68984	366939	176820	117500	94328
84	147231712	145042	77.3	3792	262287	72628	370212	185364	128100	71270
85	156743696	152712	76.9	3929	265723	78074	380324	162996	127200	79916
86	152702384	152079	81.3	3879	269813	86343	394417	170000	102000	68598
87	159611392	159611	84.2	4136	264398	91797	399615	180000	105100	67000

Column description and source of data:

(1) O&MN (value during year of obligation) - 2199 Report

(2) O&MN (NPV as of FY 1987 $000) - 2199 Report

(3) SMA - ICP MILSTEP Workload Analysis

(4) End Strength - NAVSUP Management Data Handbook

(5) 1H COG Line Items - Supply Management Report (1145 Report)

(6) 7 COG Line Items - 1145 Report

(7) Total Line Items - 1145 Report

(8) Backorders - ICP MILSTEP Workload Analysis Report

(9) MOOS - ICP MILSTEP Workload Analysis Report

(10) Total Purchase - SPCC Contracting Department Data

YEAR	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
76	600000	90000	815225	72203	618521	58819	6090	31909	29488	31041	7808
77	639758	105000	852782	73908	552458	57674	7111	32627	28050	52933	9205
78	662075	119825	896102	80977	610086	60981	7156	36168	29338	60807	8968
79	636380	130894	883085	87471	663445	70018	652	32793	33734	62516	10575
80	586010	128353	822810	90995	653421	60629	964	29893	28890	52881	10624
81	615976	171311	850695	94120	561304	86949	12354	38163	35016	65764	10910
82	643515	209030	891297	84231	451768	79774	14720	33693	36111	65070	12478
83	552374	219662	812807	87764	561603	56144	6939	33300	28699	52880	9451
84	574487	237758	852764	94270	682755	45510	6182	30857	19653	42354	9428
85	563160	263145	865919	100569	500101	56861	6790	37325	24970	40866	9500
86	575438	308829	926438	104187	651139	50283	6583	31452	15510	38431	9677
87	544332	306453	889480	107400	564082	48000	6400	29000	12000	36000	9700

Column description and source of data:

(11) 1H COG Demands - Supply Availability Analysis Report
(12) 7 COG Demands - Supply Availability Analysis Report
(13) Total Demands - Supply Availability Analysis Report
(14) Repairable Line Items - Statistical Summary Item Mgmt Report
(15) Items Selected to Support Equipment - 1145 Report
(16) Small Purchase Actions - SPCC Contracting Department Data
(17) Large Purchase Actions - SPCC Contracting Department Data
(18) Stock Purchase Actions - SPCC Contracting Department Data
(19) Spot Purchase Actions - SPCC Contracting Department Data
(20) Consumable Item Purchases - " " " "
(21) Repairable Item Purchases - " " " "

YEAR	(22)	(23)	(24)	(25)	(26)
81	1069900	0.7969	1342.5	36664	24716
82	1395100	0.8424	1656.1	59922	53571
83	1743576	0.8788	1984.0	22135	51685
84	1667359	0.9120	1806.3	19691	24656
85	1719798	0.9402	1829.2	25192	15054
86	1589205	0.9684	1641.1	39919	25826
87	1614949	1.0000	1615.0	39748	34253

Column description and source of data:

(22) NSF (value during year of obligation $000) - NAVSUP 013

(23) NSF Inflation Index - NAVSUP 013

(24) NSF (NPV as of 1987 $000,000) - NAVSUP 013

(25) Items Added during cataloguing actions - 1145 Report

(26) Items Deleted during cataloguing actions - 1145 Report

APPENDIX B. ANNUAL DATA FOR ASO

YEAR	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
73	29775524	0.3913	76094	1374864	774960	2214071	490219	76.9
74	36816736	0.4339	61804	1165404	688200	1955091	492195	73.7
75	47600816	0.4798	99210	1096404	626256	1827878	531400	69.3
76	51496816	0.5219	98672	1159260	578688	1748792	512977	69.0
77	57589728	0.5659	101767	1172628	550428	1618651	430324	72.3
78	61597313	0.6141	100305	1107912	582756	1551411	391641	74.1
79	65819376	0.6823	96467	996012	606300	1481197	371992	74.2
80	73700000	0.7926	92985	1009944	606312	1479672	370005	74.4
81	81300000	0.8691	93545	979572	599700	1460761	382412	73.3
82	88400000	0.9133	96722	978936	616776	1461804	365472	74.5
83	93134992	1.0484	88835	871932	620796	1382406	334284	75.3
84	103948464	1.0151	102402	942732	678132	1517138	361164	75.9
85	114528384	1.0264	111583	909804	766320	1443799	317484	77.7
86	114128128	1.0041	113662	908952	696024	1396745	275016	80.1
87	115503680	1.0000	115504	864504	646140	1301291	260000	81.1

Column description and source of data:

(1) O&MN (value during year of obligation) - NAVSUP Mgmnt Handbook

(2) O&MN Inflation Index - OPNAV 81

(3) OMN (NPV as of FY 1987 $000) - NAVSUP Management Handbook

(4) 1R COG demands - SDB-4, ASO

(5) 7R COG demands - SDB-4, ASO

(6) Total demands - ICP MILSTEP Workload Analysis Report

(7) Backorders - ICP MILSTEP Workload Analysis Report

(8) SMA - ICP MILSTEP Workload Analysis Report

YEAR	(9)	(10)	(11)	(12)	(13)
76	424616	60615	254401	48912	335257
77	488919	63492	247923	49749	332368
78	541442	64557	220643	51534	307790
79	561794	65253	220737	51946	305841
80	546811	66676	224309	52741	311319
81	564808	65118	206457	51250	291327
82	585826	66324	211423	52372	296695
83	604002	69162	167324	54827	301942
84	605466	69057	161500	55110	264860
85	623111	71540	158084	55104	269694
86	635238	75983	158733	59911	265536
87	647387	74613	159797	57864	258806

Column description and source of data:

(9) Program Support Items (PSI) - File Maintenance Statistics

(10) Repairable line items - ASO Management Data Handbook

(11) 1R COG line items - File Maintenance Statistics

(12) 7R COG line items - File Maintenance Statistics

(13) Total line items - File Maintenance Statistics

YEAR	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
81	14448	44621	59069	2381	2028000	0.7969	2544.9	108600
82	16508	41252	57760	2334	2510300	0.8424	2979.9	98000
83	11769	42211	53980	2352	3047600	0.8788	3467.9	106100
84	13945	53038	66983	2529	3404700	0.9120	3733.3	118300
85	15953	44856	60809	2712	3335770	0.9402	3547.9	119100
86	11479	40206	51685	2588	3509035	0.9684	3623.5	111300
87	14692	62070	76762	2714	2797518	1.0000	2797.5	112000

Column description and source of data:

(14) Large purchase actions - ASO Management Data Handbook

(15) Small purchase actions - " " " "

(16) Total purchase actions - " " " "

(17) End strength - NAVSUP Management Handbook

(18) NSF (value during year of obligation $000) - NAVSUP 013

(19) NSF inflation index - NAVSUP 013

(20) NSF obligations (NPV as of FY 1987 $000,000) - NAVSUP 013

(21) MOOS - NAVSUP Management Data Handbook

APPENDIX C. QUARTERLY DATA FOR SPCC

Column description and sources of data

(1) O&MN (NPV as of FY 1987 $000)- 2199 Report

(2) 1H COG line items -1145 Report

(3) 7 COG line items - 1145 Report

(4) Total line items - 1145 Report

(5) 1H COG demands - M67 Report

(6) 7 COG demands - M67 Report

(7) Total demands - M67 Report

(8) SMA - M67 report

(9) Repairable line items - ICP MILSTEP Workload Analysis Report

YEAR		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
73	1	22540	117477	40391	375420					
	2	24211	116398	41182	376606					
	3	20808	110521	41300	367254					
	4	28637	103579	48352	365464					
74	1	22691	108663	48662	363126					
	2	24635	107761	49557	359825					
	3	24494	107596	49903	357529					
	4	30138	105809	57097	355963					
75	1	31965	104488	58247	359752					
	2	28111	104395	62720	360429					
	3	27083	105820	63288	362889					
	4	26861	106132	63517	364223					
76	1	29604	109541	60864	365952	144200	20400	204616	73.4	
	2	28765	110109	61652	368415	148300	22600	200894	74.8	
	3	29337	110125	62239	369212	152300	22200	207723	76.0	
	4	29667	267263	63396	366691	155200	24800	201992	79.0	
7T		22023	272502	64397	369075	160012	24300	215089	78.7	
77	1	30554	267231	66218	363187	151202	25300	201665	77.5	

	2	30535	273071	67093	368545	161167	24900	214199	77.3	
	3	29125	277345	68933	372147	158532	26800	213389	77.4	
	4	30819	278920	69818	374699	168857	28000	223529	77.0	
78	1	27682	281343	69476	371021	159811	27320	214186	77.7	
	2	27868	283038	70405	378928	158307	27290	211891	78.0	
	3	28680	285129	70690	381155	175014	32740	240460	76.8	
	4	30928	286891	71575	384947	168943	32475	229565	75.5	
79	1	29452	288392	72497	386984	163944	29109	220251	75.7	
	2	30997	289291	74221	389245	175326	34570	239944	76.1	
	3	30777	264117	76762	367103	147808	34152	211980	72.2	
	4	30526	263275	76285	368481	149302	33063	210910	72.7	
80	1	25919	261512	77659	368471	141470	30474	196464	72.8	
	2	28080	263559	78158	372205	143883	31685	203814	71.5	
	3	28760	265533	78627	374538	142852	32778	202771	71.8	
	4	33379	266067	79035	375948	157805	33416	219761	73.2	
81	1	28236	267565	79918	378894	149714	35068	205945	72.2	91993
	2	27149	269546	80774	381937	140888	36860	198218	71.1	93381
	3	26546	292123	61089	387128	170319	51235	234675	72.7	94046
	4	33507	294675	61270	390120	155055	48148	211857	73.8	94120
82	1	27785	295515	62309	391138	159590	51073	220878	73.1	95822
	2	30232	295328	62583	393311	161060	48367	219208	73.4	80986
	3	28509	295094	62965	393547	168385	53382	232451	72.6	82185
	4	32162	297225	63714	396475	154480	56208	218760	75.6	84231
83	1	28234	293147	64800	393217	137646	50831	200030	74.0	84316
	2	28926	293995	66967	396932	143849	57180	211755	73.8	85512
	3	32995	266313	68011	370264	138752	57118	206274	75.9	87023
	4	31866	264191	68984	366939	132127	54533	194748	76.9	87764
84	1	31124	262457	69681	365660	142298	60099	213184	76.8	88998
	2	40799	264085	70868	368653	146270	59531	215057	77.0	90439
	3	40056	261262	71743	367872	140653	56918	208202	78.3	92155
	4	33062	262287	72628	370212	145266	61210	216321	77.2	94270
85	1	36470	264159	74291	374214	130846	58279	199006	75.0	97120
	2	39399	265838	75717	377682	137805	60382	208481	77.2	98564
	3	37796	268468	77370	381868	142896	69737	222094	76.4	100281

	4	39047	265723	78074	380324	151613	74747	236338	78.9	100569
86	1	37084	262626	79032	378253	143213	73002	227664	79.0	102949
	2	41729	264017	80727	381356	137073	74464	221353	81.1	104461
	3	34219	266276	83548	387854	148077	80471	239316	82.3	104621
	4	39047	269813	86343	394417	147075	80892	238105	82.8	104187
87	1	37261	263131	86909	389112	131872	76006	216972	83.6	105854
	2	39445	262854	88239	393918	137801	76525	222893	83.9	106198
	3	36229	263821	89683	396258	142191	77762	230066	84.6	107100
	4	46677	264398	91797	399615	132468	76160	219549	84.8	107400

APPENDIX D. QUARTERLY DATA FOR ASO

Column description and source of data:

(1) O&MN (NPV as of FY 1987 $000) - 2199 Report

(2) Program Support Items (PSI) - File Maintenance Statistics

(3) 1R COG line items - File Maintenance Statistics

(4) 7R COG line items - File Maintenance Statistics

(5) Total line items - File Maintenance Statistics

(6) Repairable line items - Statistical Summary Item Report

(7) Total demands - ICP MILSTEP workload analysis report

(8) SMA - ICP MILSTEP workload analysis report

YEAR		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
76	1	25972	411723	253067	49887	336602			
	2	27910	412539	253522	50040	336549			
	3	21242	420912	255504	50873	338810			
	4	23548	424616	254401	48912	335257			
7T		24172	430500	253543	48948	334913			
77	1	36755	435764	271700	48705	355042			
	2	20219	466260	262756	49236	346844			
	3	22482	482589	252180	49668	336417			
	4	22310	488919	247923	49749	332368			
78	1	32815	521117	228724	49816	313613			
	2	22054	536000	218625	50232	304094			
	3	21105	538840	220058	50400	306073			
	4	24323	541442	220643	51534	307790			
79	1	35802	551125	219305	51100	304131			
	2	20914	553261	219667	51325	302912			
	3	19478	557403	219974	51465	303707			
	4	20274	561794	220737	51946	305841			
80	1	34662	565238	221595	51967	307541			
	2	19095	563005	222806	52270	308945			

	3	18538	563516	223804	52571	310185			
	4	20690	546811	224309	52741	311319			
81	1	30286	559133	215209	52858	302125	67329	350767	72.9
	2	21462	560100	210516	51922	296685	66388	365742	72.8
	3	19350	562284	212264	52271	298705	67107	368313	74.0
	4	22448	564808	206457	51250	291327	66199	375939	73.5
82	1	26904	579349	212813	52016	298552	66112	369000	73.8
	2	29457	580481	213867	52008	298993	66508	358000	74.1
	3	19235	584099	211308	52231	296416	67000	347000	74.3
	4	21196	585826	211423	52372	296695	67142	340000	74.5
83	1	24228	593959	162260	52372	297207	67380	337055	74.7
	2	22911	598562	165124	53639	298665	67971	349873	75.4
	3	21091	601664	165563	54079	299340	68911	348029	75.5
	4	20605	604002	167324	54827	301942	69703	347449	74.7
84	1	33273	597296	167762	55172	302793	70157	348092	74.6
	2	23809	601699	167867	55332	260566	70490	380615	74.2
	3	21723	603263	166370	55850	263351	70791	349481	74.8
	4	23598	605466	161500	55110	264860	70024	438950	75.9
85	1	31975	609452	159357	55997	267467	70100	344807	76.9
	2	33327	610812	157221	55101	268817	71256	376171	77.9
	3	19721	618773	155698	54981	268468	72175	368771	77.2
	4	26855	623111	158084	55104	269694	72605	354050	78.8
86	1	38915	632338	155206	55021	260957	73331	331443	77.8
	2	21643	633682	156118	55516	262403	73384	359854	81.1
	3	25576	634225	156673	55934	260364	73398	360973	80.7
	4	27529	635238	158733	59911	265536	73421	344475	80.6
87	1	28987	639810	159081	56344	254705	73155	314977	80.3
	2	27200	640187	158981	56701	256896	73335	327527	80.7
	3	28955	647318	159884	57422	257641	73550	327527	81.5
	4	30361	647387	159797	57864	258806	73680	346001	81.8

APPENDIX E. SCATTER PLOTS

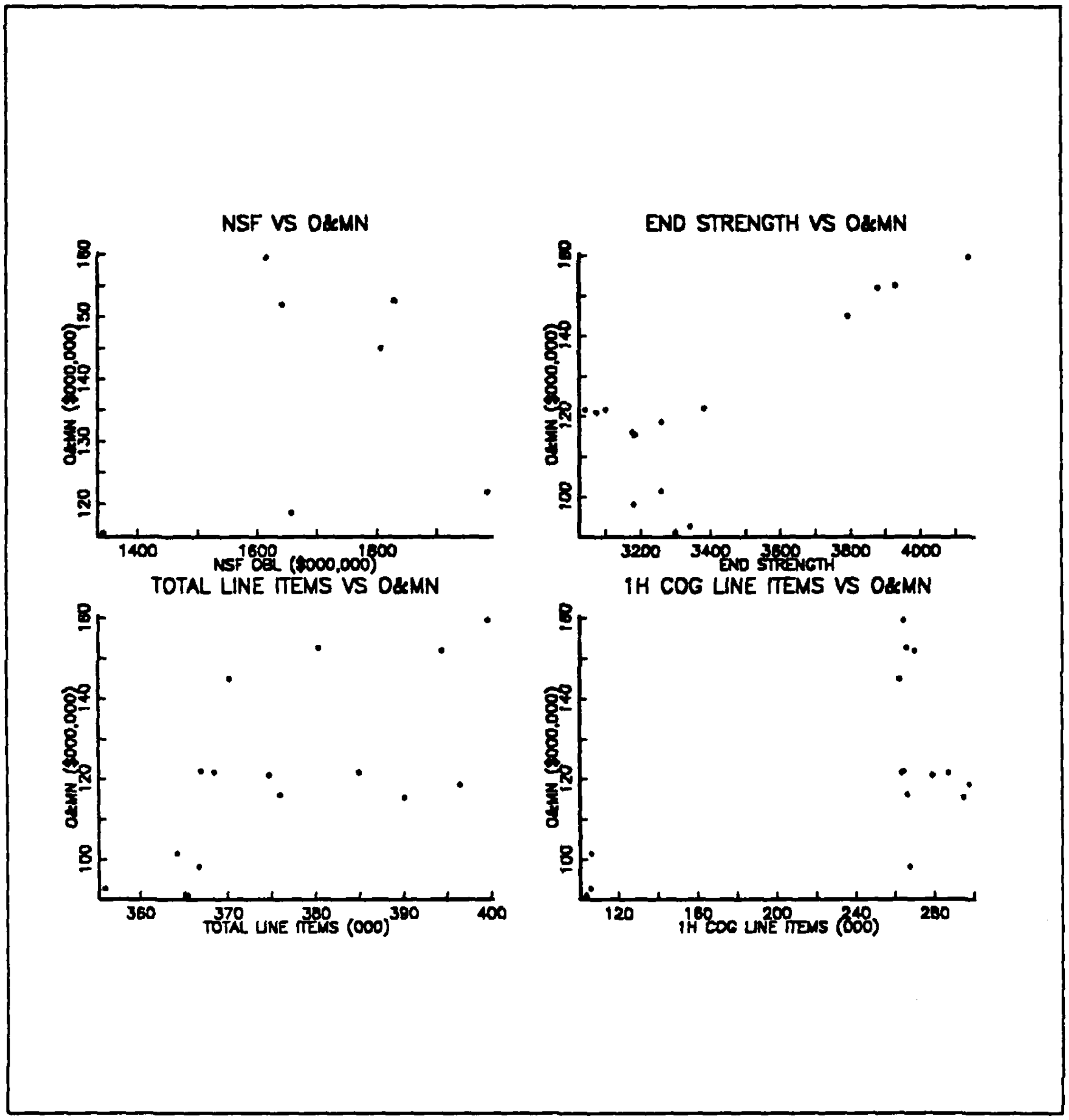

Figure 10. Scatter Plots of SPCC Annual Variables.

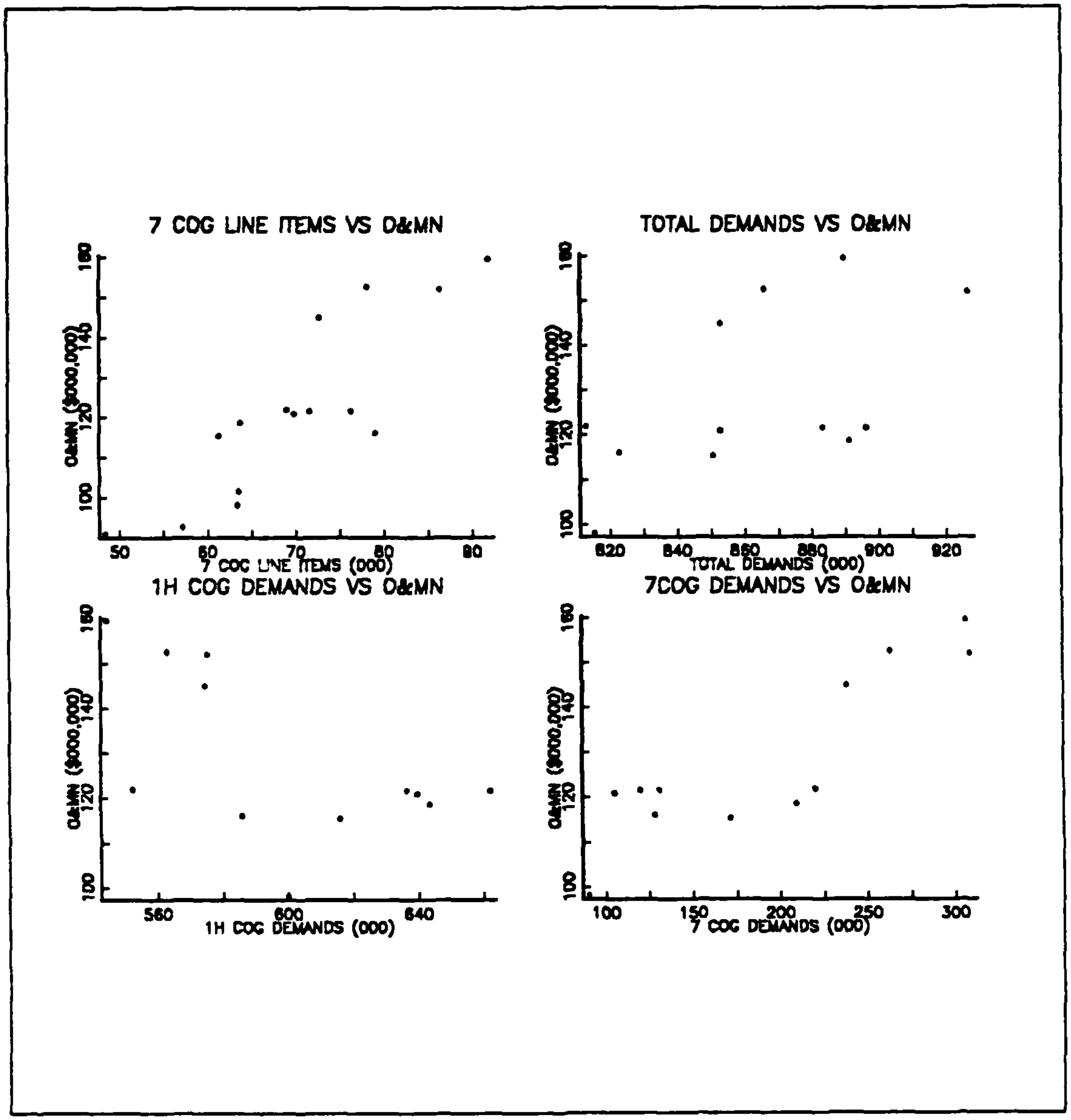

Figure 11. Scatter Plots of SPCC Annual Variables.

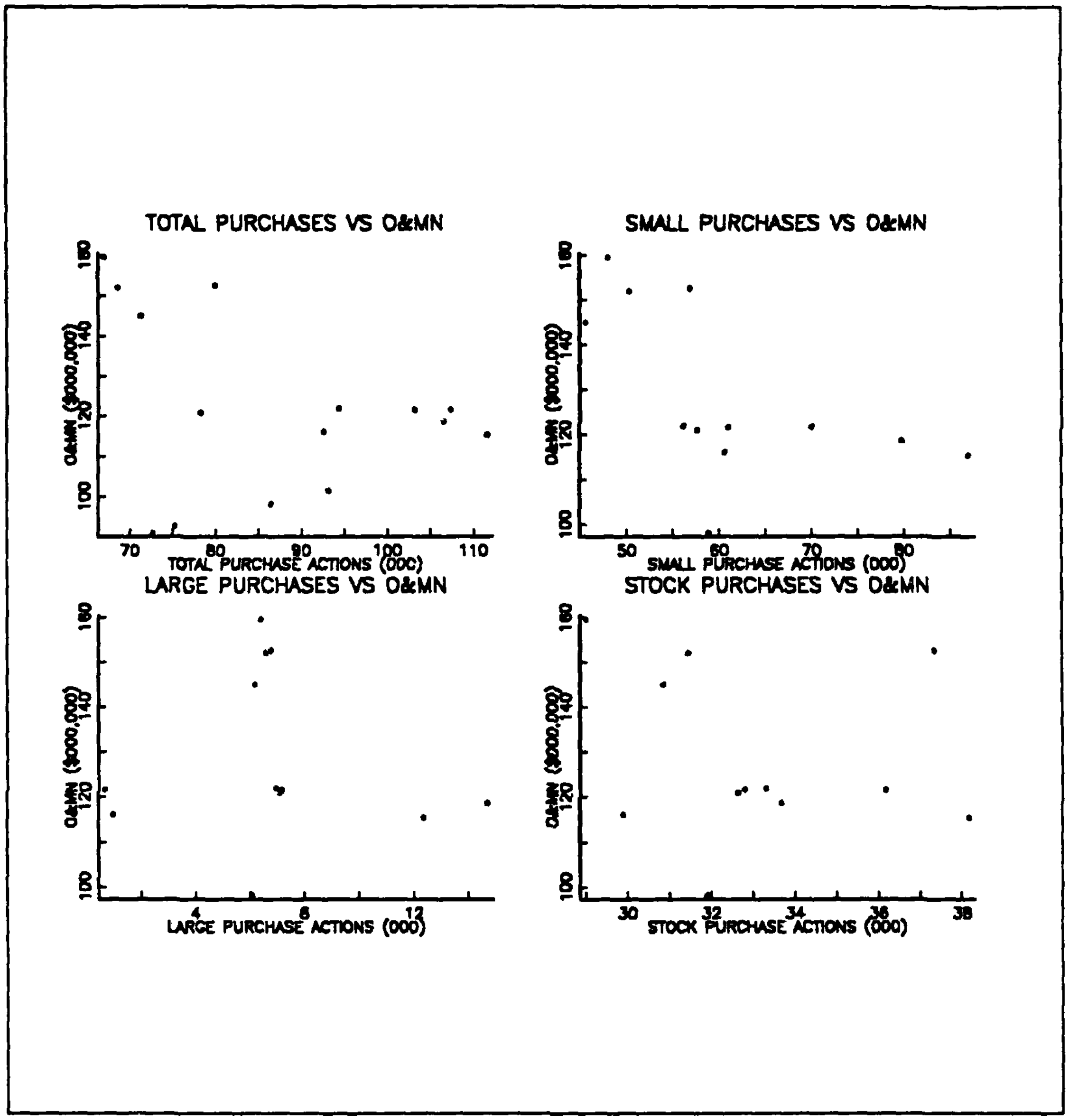

Figure 12. Scatter Plots of SPCC Annual Variables.

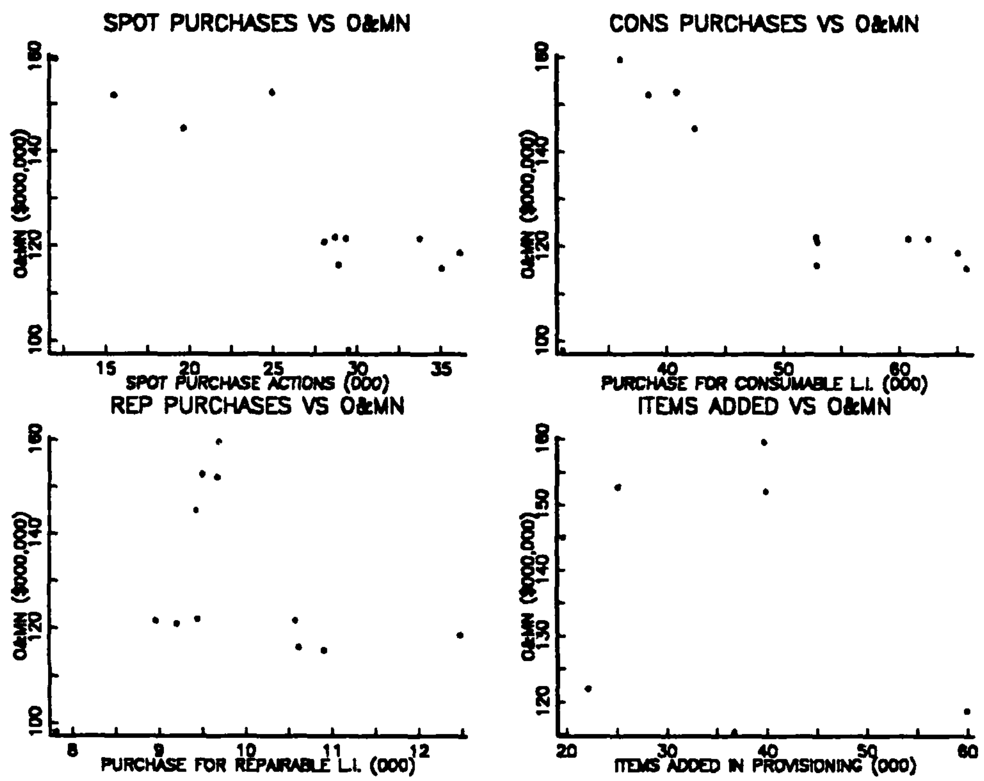

Figure 13. Scatter Plots of SPCC Annual Variables.

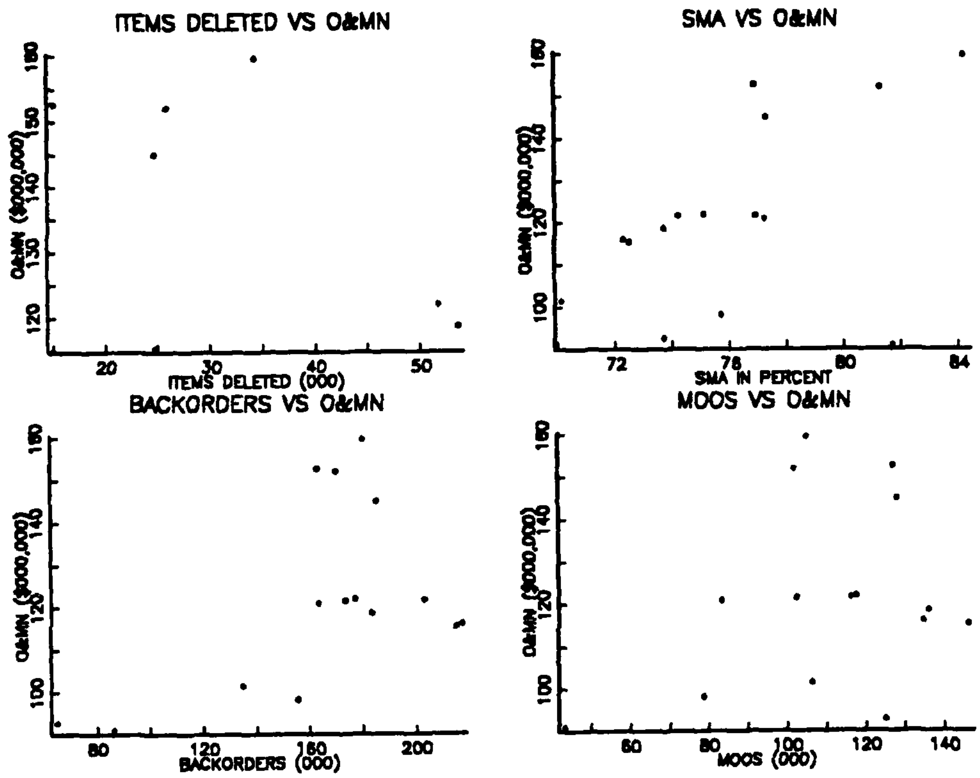

Figure 14. Scatter Plots of SPCC Annual Variables.

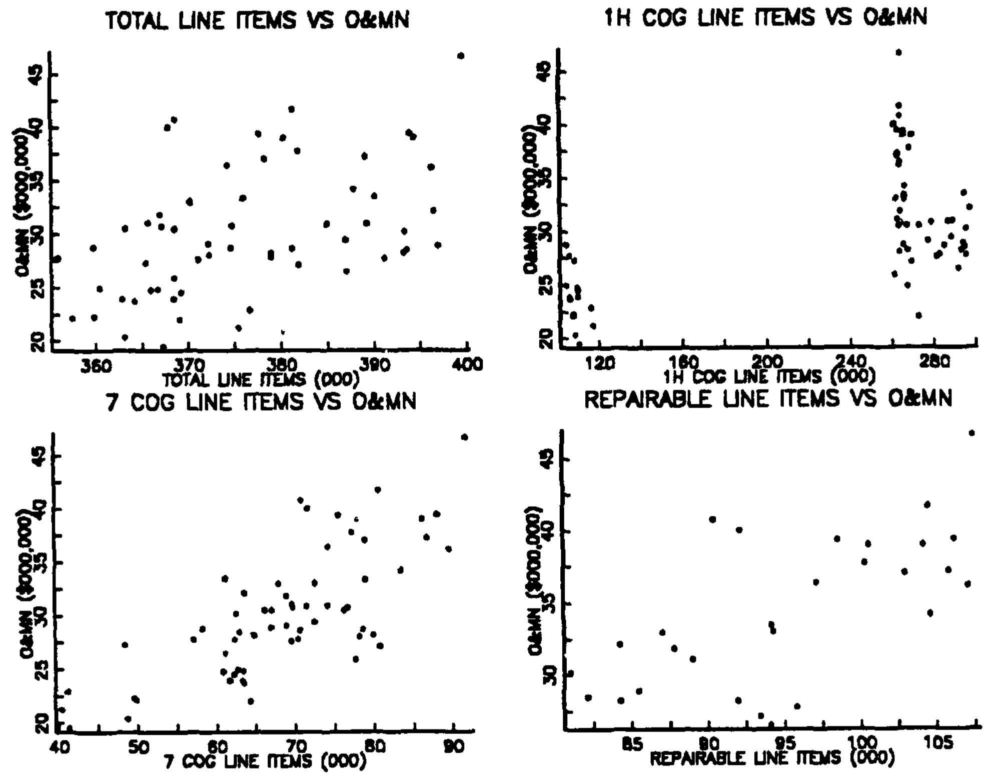

Figure 15. Scatter Plots of SPCC Quarterly Variables.

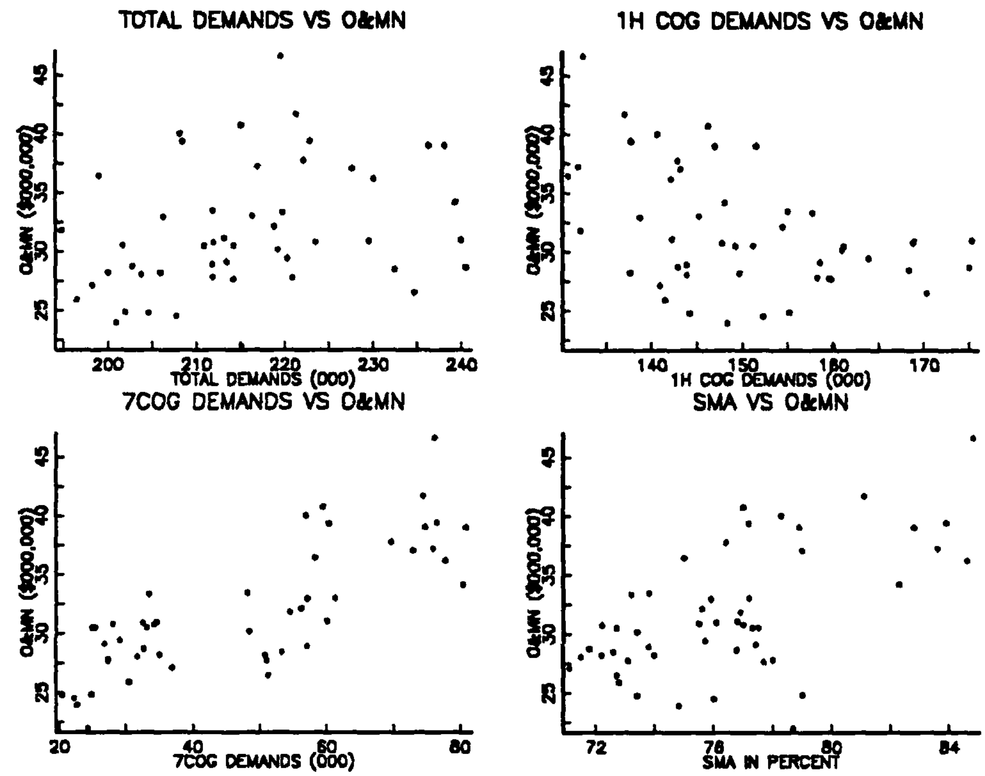

Figure 16. Scatter Plots of SPCC Quarterly Variables.

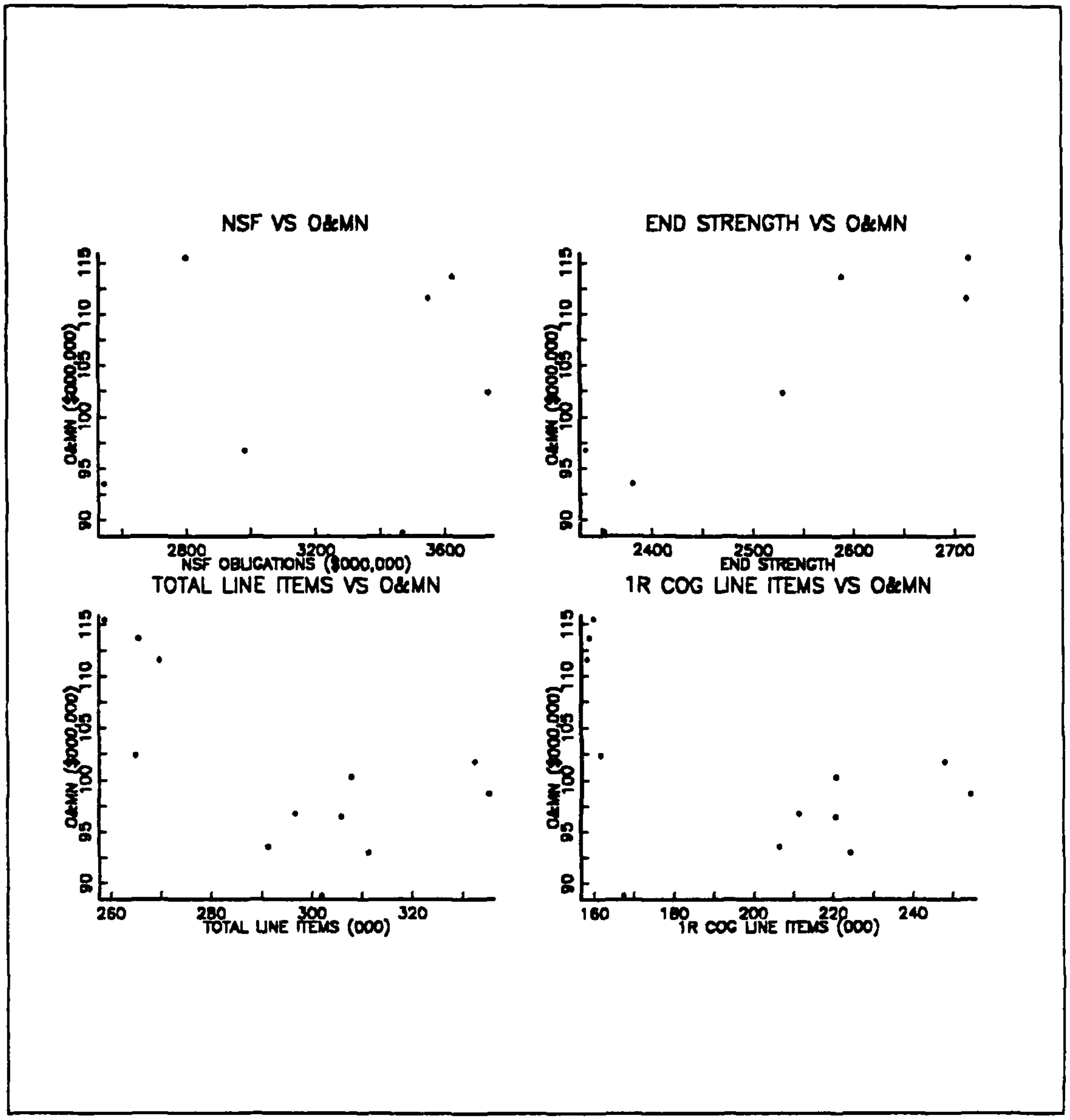

Figure 17. Scatter Plots of ASO Annual Variables.

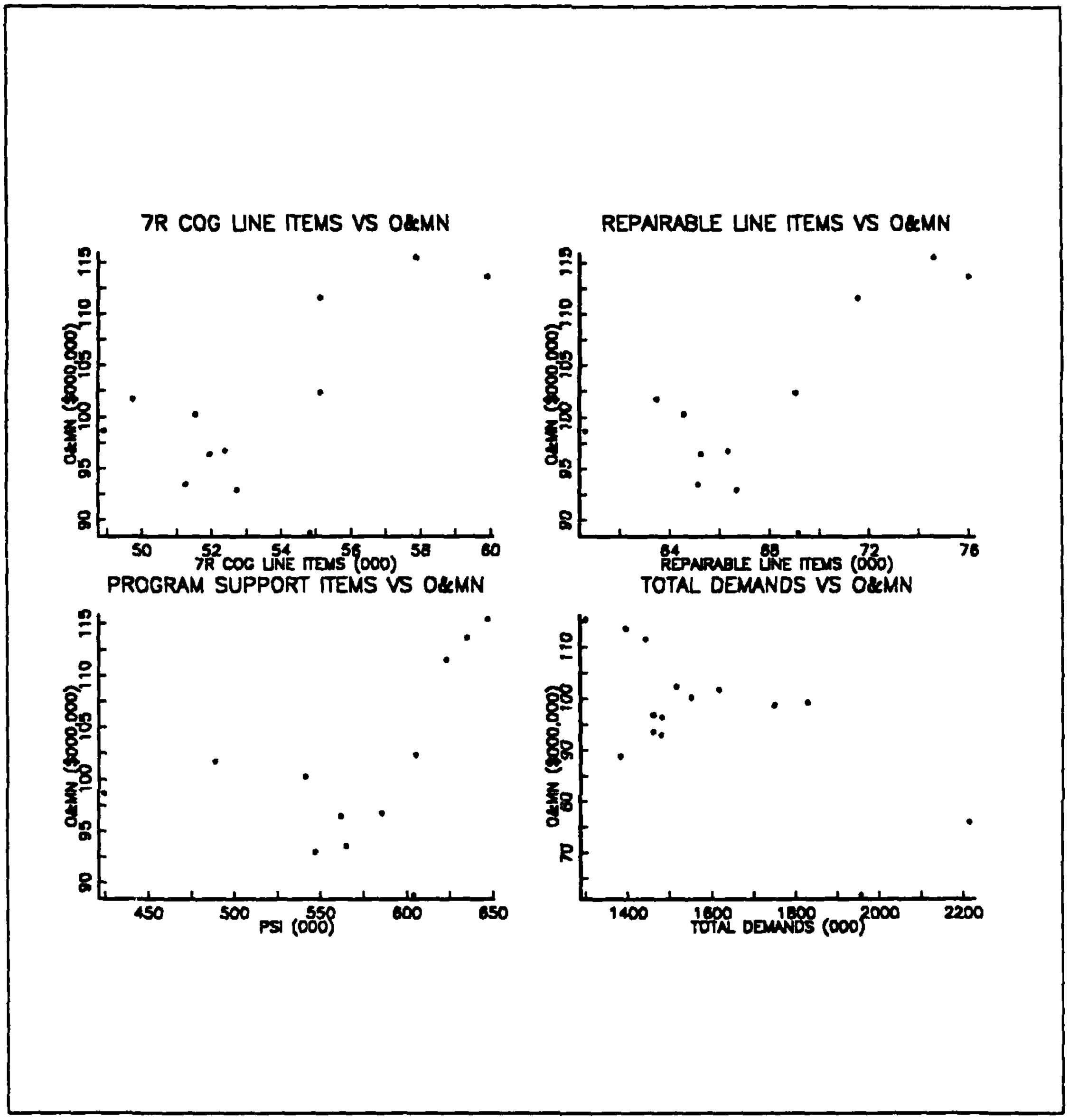

Figure 18. Scatter Plots of ASO Annual Variables.

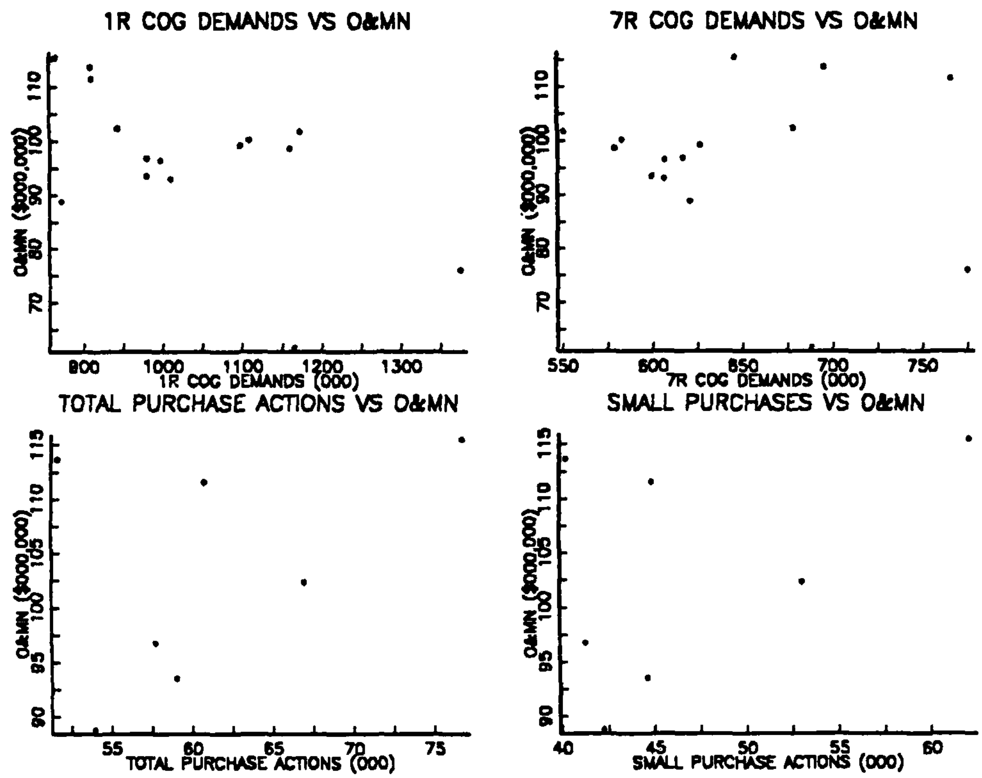

Figure 19. Scatter Plots of ASO Annual Variables.

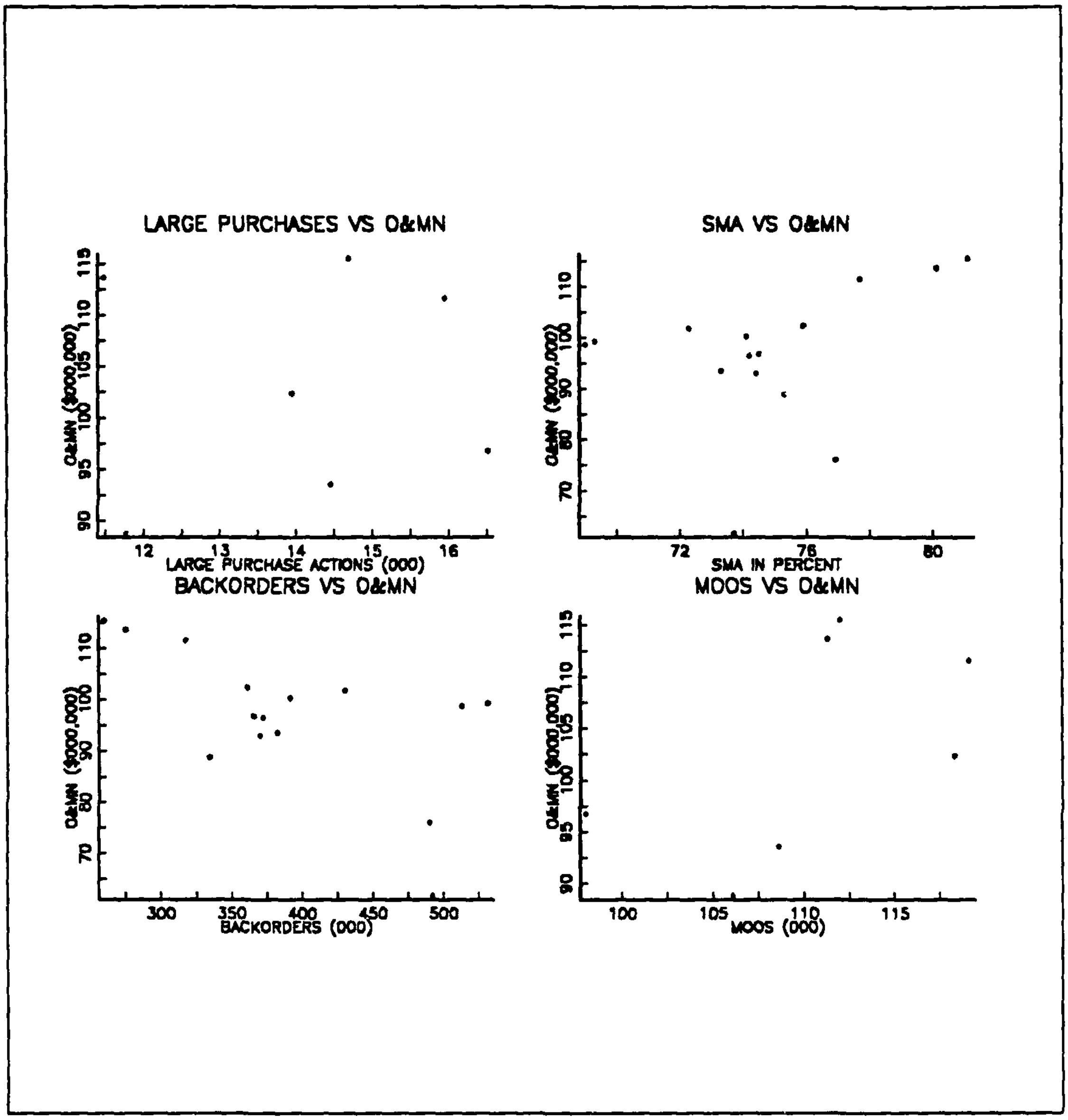

Figure 20. Scatter Plots of ASO Annual Variables.

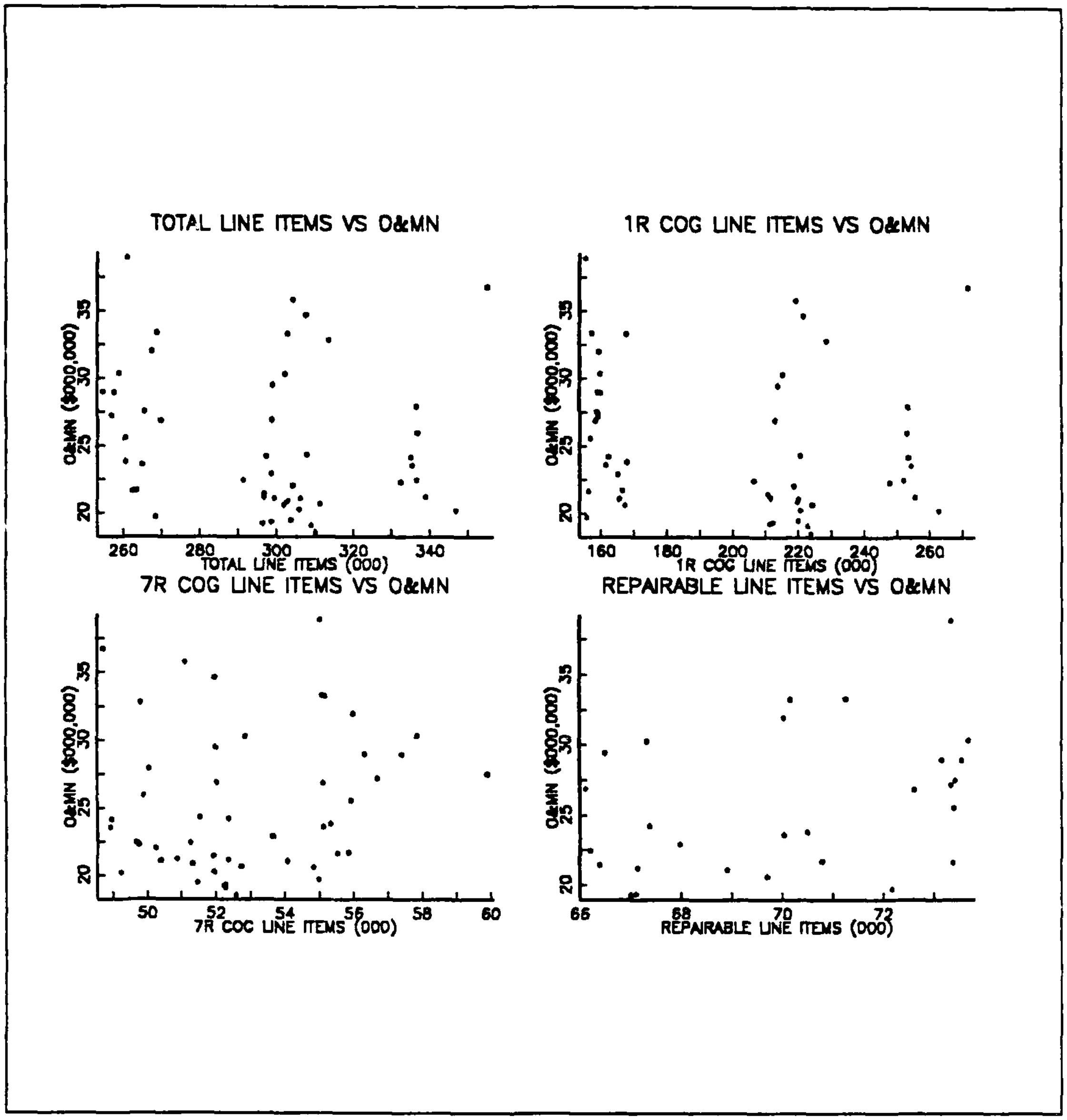

Figure 21. Scatter Plots of ASO Quarterly Variables.

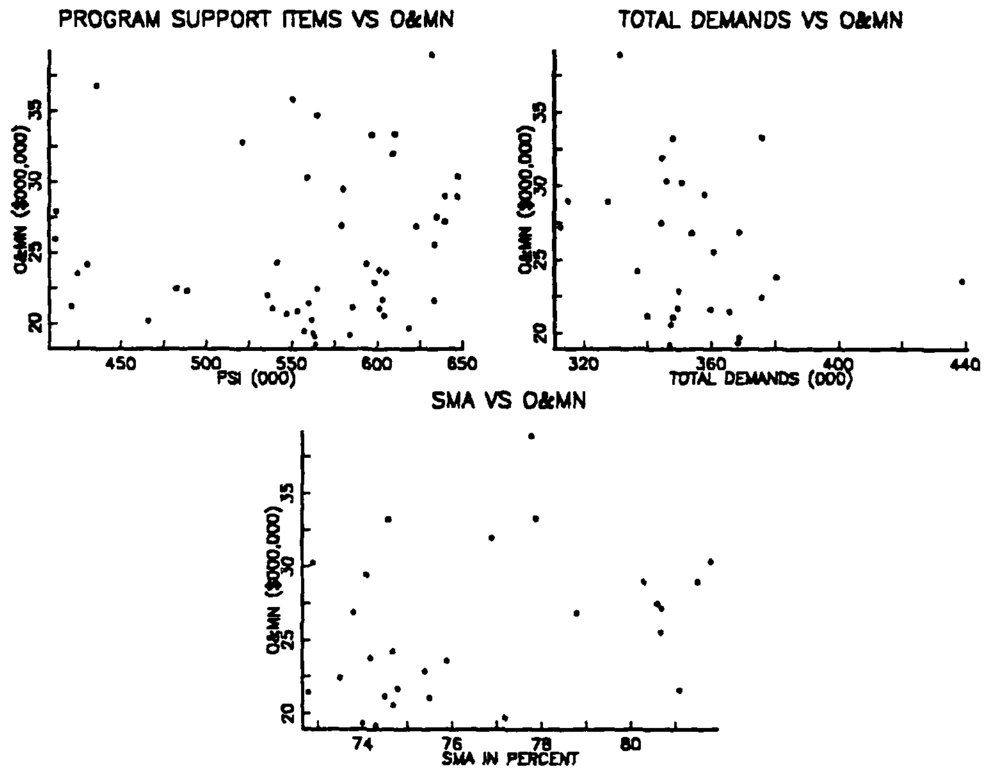

Figure 22. Scatter Plots of ASO Quarterly Variables.

LIST OF REFERENCES

1. *Strategic Plan for FY 88*, Naval Supply Systems Command, Washington, D.C.

2. *Corporate Plan*, Navy Aviation Supply Office, Philadelphia, PA.

3. *Activity Management Report*, Ships Parts Control Center, Mechanicsburg, PA.

4. Whitaker, J.B., Rear Admiral, SC, USN, *Workload Drivers at Navy Inventory Control Points*, Meeting, Naval Supply Systems Command, Washington, D.C.,19 November 1987.

5. Nelson, T., CDR, SC, USN, SUP-042, *Memorandum*, Naval Supply Systems Command, Washington, D.C., 22 December 1987.

6. Mason, Robert D., *Statistical Techniques in Business and Economics*, Richard D.Irwin, Inc., 1975.

7. Mosteller, Frederick and Tukey, John W., *Data Analysis and Regression*, Addison-Wesley Publishing Company, 1977.

8. Draper, Norman R. and Smith, Harry I., *Applied Regression Analysis*, John Wiley and Sons, 1966.

9. Weisberg, Sanford, *Applied Linear Regression*, John Wiley and Sons, Inc., 1980.

10. Degroot, Morris H., *Probability and Statistics, Second Edition*, Addison-Wesley Publishing Company, 1975.

BIBLIOGRAPHY

Chambers, John M., Cleveland, William S., Kleiner, Beat, and Tukey, Paul A., *Graphical Methods For Data Analysis,* Wadsworth International Group, 1983.

Schatzoff, Martin and Lane, Thomas P., *Regression Analysis In GRAFSTAT,* IBM Thomas J. Watson Research Center, NY.

Minitab Reference Manual, Minitab, Inc., State College, PA.

INITIAL DISTRIBUTION LIST

	No. Copies
1. Defense Technical Information Center Cameron Station Alexandria, VA 22304-6145	2
2. Library, Code 0142 Naval Postgraduate School Monterey, CA 93943-5002	2
3. CDR Mark L. Mitchell, SC, USN, Code SUP 042E Naval Supply Systems Command Department of the Navy Washington, D.C. 20376	3
4. Defense Logistics Information Exchange U.S. Army Logistics Management Center Fort Lee, VA 23801	1
5. Commanding Officer Aviation Supply Office 700 Robbins Avenue Philadelphia, PA 19111	1
6. Commanding Officer Navy Ships Parts Control Center Mechanicsburg, PA 17055	1
7. LT Edgardo T. deGuia, SC, USN, Code SDB-4 Aviation Supply Office 700 Robbins Avenue Philadelphia, PA 19111	3
8. LCDR Robert L. Gilson, SC, USN, Code 0412 Navy Ships Parts Control Center Mechanicsburg, PA 17055	2
9. Prof. Alan W. McMasters, Code 55Mg Department of Operations Research Naval Postgraduate School Monterey, CA 93943-5000	3
10. Prof. Dan C. Boger, Code 54Bo Department of Administrative Sciences Naval Postgraduate School Monterey, CA 93943-5000	1